SUPPORT FOR THE DEVELOPMENT AND IMPLEMENTATION OF AN ACCESS MANAGEMENT PROGRAM THROUGH RESEARCH AND ANALYSIS OF COLLISION DATA

Final Report

Submitted by:
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In cooperation with
The University of South Carolina and the Citadel

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November 11, 2015

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16. Abstract
The South Carolina Access and Roadside Management Standards (ARMS) provides standards and guidelines for permitting access encroachments onto SCDOT right-of-way. In April, 2013, SCDOT initiated research that would be used to update this manual with the intent that recommended changes could result in a reduction in crashes, injuries, and fatalities on South Carolina roadways. The research examined current and historical practices used by other transportation agencies with regard to access management. Using empirical data collected along several corridors that ranked highest in driveway related crashes, the researchers statistically analyzed and identified the correlation of access issues with crash data. Crash data were associated with driveways using complex Geographic Information System (GIS) modeling tools. The statistical analysis identified several significant independent variables that influence crash rates either positively or negatively. The results indicate that increasing the distance between driveways, increasing the number of entry lanes, and having a raised median will decrease driveway related crashes. Conversely, increasing driveway width, corridor volume and corridor speed limit will increase crashes. Similarly, a driveway with high turnover land use, a driveway with full access (as opposed to right-in right-out), and the presence of nearby signalized intersections will increase crashes. A micro-simulation analysis was used to investigate the operational performance of different driveway spacing policies adopted by various DOTs in the US. Experimental results indicate that driveway spacing has direct influence on the average travel speed of a corridor. Since reduced driveway spacing negatively impacts corridor travel speed, selection of a minimum spacing should consider its effect on the operational performance of the corridor. Benefit-cost analyses of two different access modification strategies following the Highway Safety Manual (HSM) procedures suggest that it is beneficial to convert a TWLTL to a raised median. Similarly, it is beneficial to reduce the driveway density on a corridor. The research also reviewed SCDOT access waiver procedures. While the current process suffices based on our literature review it is evident that this process could be significantly streamlined and enhanced with a paperless system. Based on research findings, recommended changes to SCDOT Access and Roadside Management Standards (ARMS) are presented. It is anticipated that implementation of the findings of this research will result in long-term economic benefits, and improved traffic flow and safety.

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EXECUTIVE SUMMARY

The South Carolina Access and Roadside Management Standards (ARMS) provides standards and guidelines for permitting access encroachments onto SCDOT right-of-way. In April, 2013, SCDOT initiated research that would be used to update this manual with the intent that recommended changes could result in a reduction in crashes, injuries, and fatalities on South Carolina roadways. The enhancement in safety is expected to improve traffic flow while minimizing negative economic impacts on land use. It is anticipated that implementation of the findings of this research will result in long-term economic benefits, and improved traffic flow and safety.

Clemson University in collaboration with the University of South Carolina and the Citadel conducted this research for SCDOT. The researchers examined current and historical practices used by other transportation agencies with regard to access management. Using empirical data collected along several corridors that ranked highest in driveway related crashes, the researchers statistically analyzed and identified the correlation of access issues with crash data from 2012. Crash data were associated with driveways using complex Geographic Information System (GIS) modeling tools. Historical crash data before 2012 were not used in the final analyses because of spatial accuracy problems with previous crash reporting procedures. The new South Carolina Collision and Ticket Tracking System (SCCATTS) has enhanced crash location data significantly. Accurate crash locations are critical for associating crashes with driveways.

The statistical analysis identified several significant independent variables that influence crash rates either positively or negatively. The results indicate that increasing the distance between driveways, increasing the number of entry lanes, and having a raised median will decrease driveway related crashes. Conversely, increasing driveway width, corridor volume and corridor speed limit will increase crashes. Similarly, a driveway with high turnover land use, a driveway with full access (as opposed to right-in right-out), and the presence of nearby signalized intersections will increase crashes.

The research also reviewed SCDOT access waiver procedures. The current waiver application process is paper based and requires multiple reviews at various levels. Each county in South Carolina manages the waiver application in a similar manner. While the current process suffices based on our literature review it is evident that this process could be significantly streamlined and enhanced with a paperless system.

In current practice, states have adopted differing minimum driveway spacing guidelines and these values are based on a variety of criteria, such as volume on the adjacent roadway, trip generation from driveways, posted speed limit, land use, and access type. This study used VISSIM, a micro-simulation tool, to investigate the operational performance of different driveway spacing policies adopted by various DOTs in the US. Experimental results indicate that driveway spacing has direct influence on the average travel speed of a corridor. Since reduced driveway spacing negatively impact corridor travel speed, selection of a minimum spacing should consider its effect on the operational performance of the corridor.
Benefit-cost analyses of two different access modification strategies following the Highway Safety Manual (HSM) procedures suggest that it is beneficial to convert a TWLTL to a raised median. Similarly, it is beneficial to reduce the driveway density on a corridor. The HSM analysis used in this study only considered safety benefits of access management strategies. It did not consider the impact of different access management strategies on surrounding businesses. Based on research findings, recommended changes to SCDOT Access and Roadside Management Standards (ARMS) are presented for consideration.

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CHAPTER 1: INTRODUCTION

1.1 Introduction and Problem Statement

Access management is defined as a "set of techniques designed to manage the frequency and magnitude of conflict points at residential and commercial access points. The purpose of an access management program is to balance the mobility required from a roadway facility with the accessibility needs of adjacent land uses." (Janoff, 1982) Roads with poor access management experience more traffic crashes, negative impacts for adjacent property owners, and loss of public and private investment in the roadway system. National studies have shown that crash rates are adversely affected by poor access management. The NCHRP 420 report indicated that crash rates increase significantly in relation to the number of access points per mile; data from 37,000 crash records indicated that there are 30% more crashes when the number of access points increases from 10 to 20 access points per mile. The data from this study showed that the number of crashes quadrupled when the number of access points increased from 10 to 60 access points per mile. Many other studies have documented how uncontrolled access management results in higher crash rates and degraded traffic operation. Recognizing the importance of having proper access management, many studies have developed and assessed techniques to help balance the roadways' role of navigating traffic safely and efficiently while allowing adequate property access.

The South Carolina Access and Roadside Management Standards (ARMS) provides standards and guidelines needed for access encroachments onto SCDOT right-of-way. Improvements to this manual are needed in an effort to reduce crashes, injuries, and fatalities on South Carolina roads. Of particular concern are access waivers that are granted in cases of undue hardship caused by strict adherence to the ARMS (Chapter 1, Section 1E). The SCDOT would like to ensure that potential safety and operational consequences are understood so that an informed decision can be made when granting or denying a waiver. Informed decisions need to be supported through research and analysis of collision data. This report documents the findings of collaborated research conducted by Clemson University, the University of South Carolina, and The Citadel.

1.2 Research Objectives

The primary goal of this research is to improve SCDOT access management practices resulting in a reduction in crashes, injuries, and fatalities on South Carolina roadways. The anticipated enhanced safety will also improve traffic operations by reducing conflicts. A list of objectives for accomplishing the primary goal is included below.

1. Analyze the most recent 3 years of crash data to identify access-related problems that likely contribute to crashes. This data will be categorized contextually by crash causal factors and roadway characteristics to establish any pattern of frequency or trends on various roadway types;
2. Identify and conduct a detailed safety operational analysis of the top 10 -15 corridors across the state with the highest access related crash types;
3. Review current literature, AASHTO design guidelines, Federal Highway Administration technical material, and other state DOT best practices related to access management;

4. Research and identify any statutory support or restrictions for access management;
5. Review literature to identify typical economic impacts that result from access restriction. This economic impact will be compared to the economic impact of the crashes;
6. Analyze waiver applications to identify types of access requests and subsequently analyze their safety and operational implications. ;
7. Develop an effective means to incorporate research recommendations into the next edition of the ARMS Manual;
8. Develop a final report to include recommendations for a successful access management program to be implemented by SCDOT as well as recommendations on coordination with local governments to ensure desirable access management practices and processes are in place.

1.3 Benefits of This Research

The literature review presented in Chapter 2 indicates that there is a vast amount of information available related to access management strategies and policies that have been implemented around the country and abroad. Many of these strategies have already been implemented in South Carolina and are published in the ARMS manual. The analysis of crash data from several South Carolina corridors will yield support for which policies, standards, and guidelines have positive safety, operational, and economic impacts. Additionally, the research identifies recommended changes to the ARMS manual which should result in long-term safety enhancements while improving traffic operations and providing substantial cost savings to the state of South Carolina. Further, the implementation of a context sensitive access management program outlined Chapter 7 will help to assure that the most appropriate strategies are used in a particular situation. It is anticipated that this access management program will be shared with municipalities so that access management can be included in initial municipal planning.

1.4 Report Organization

This report is organized into seven chapters. Chapter 2 provides a review of relevant literature and the results of a survey of states. Chapter 3 discusses the analysis methodology, and the design of the Geographic Information System (GIS) data layers required to support the analysis. The chapter also provides summary statistics of the analysis corridors. Chapter 4 describes the analysis and model development. Chapters 5 and 6 discuss operational and economic benefits of access management respectively. Chapter 7 outlines a context sensitive access management program and provides recommended guidelines and changes to ARMS based on the results of the research. Chapter 8 gives recommendations and conclusions as well as discusses future research possibilities.

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CHAPTER 2: LITERATURE REVIEW AND SURVEY OF STATES

2.1 Policies/Programs/Legal Requirements

2.1.1 Waivers

When administering driveway regulation programs, agencies may face a variety of site-related issues and proposed solutions that are inconsistent with adopted standards or engineering practices (Gluck and Lorenz, 2010). When this situation arises, applicants may apply for a waiver (or exception) to the agency's regulations. Therefore, procedures for considering deviations from standards, along with criteria that specify when a variance may be granted, are important aspects of an effective driveway regulation program (Williams, 2002).

Eisdorfer and Siley (1996) believed that the ultimate goal of an effective variance process is to "reach a solution that the agency can approve for the specific location, as well as other similar locations when comparable circumstances arise in the future." They suggest that access variances may be appropriate under following general situations:

- **Unreasonableness of strict application**—Where strict application of access management standards will result in an outcome that both the applicant and permitting authority can agree is unreasonable.
- **Existing substandard conditions**—Where existing conditions, such as geometric deficiencies of the abutting highway, are substandard and not attributable to the applicant.
- **Existing environmental, economic, or social constraints**— Where compliance with standards is constrained due to conditions such as limited right-of-way, wetlands, waterways, historic districts, utility conflicts, topographical constraints, and environmentally sensitive areas.
- **Uniqueness of the situation**—Where a situation precludes compliance with standards that are rarely if ever encountered and, by virtue of its unique nature, would not likely set an undesirable precedent.
- **Conflicts between the requirements of agencies having jurisdiction**—Where the requirements of one or more regulatory agencies conflict, such as between transportation features and environmental policies.
- **Near the threshold**—Where a site may straddle a boundary that results in a change of standards, such as a site having frontage that is affected by two separate access categories with different driveway spacing requirements.
- **Voluntary upgrades**—Where applicants have access and could advance their project without triggering the need for a driveway permit, but would like to improve the existing condition (in such situations, lack of willingness to provide a variance may cause the applicant to leave the existing condition unimproved). Consistency in administering variances is critical because inconsistent or infrequent application of standards makes them vulnerable to legal challenges.

New provisions regarding access waivers were included in The South Carolina DOT's *2008 Access and Roadside Management Standards*. In South Carolina, there is no fee to receive an access waiver in South Carolina nor is there a certain waiting period for the access waiver to be approved. Access waivers are placed in a queue and depending on the length of the queue the approval process could take a couple of days up to a couple of weeks. To request an access waiver, the applicant must complete the request form (found in Appendix C of the SCDOT ARMS Manual, 2008) and attach it to the permit application. The request for an access waiver should describe the undue hardship that will be placed on the applicant if a waiver is not granted. The access waiver is sent to the District Office for initial review and approval by the District Engineering Administrator (DEA). Once approved by the DEA, the access waiver is sent back to the County Maintenance Office for a final review. The Resident Maintenance Engineer (RME) must give the final approval making the access waiver approved. A waiver will be granted only if the following is determined:

- Denial of the waiver will result in loss of reasonable access to the site.
- The waiver is reasonably necessary for the convenience and welfare of the public.
- All reasonable alternatives that meet the access requirements have been evaluated and determined to be infeasible.
- Reasonable alternative access cannot be provided.
- The waiver will not result in any violations of pedestrian accessibility in accordance with the ADAAG

If a waiver is approved, the reasons for granting the waiver and any recommendations given by the Department shall be clearly stated and included in the Department files. Restrictions and conditions on the scope of the permit should be imposed as required in order to keep potential safety hazards to a minimum. The encroachment permit may contain specific terms and conditions providing for the expiration of the waiver if in the future the grounds for the waiver no longer exist (SCDOT, 2008).

2.1.2 Traffic Impact Studies

According to the *Access Management Manual* (TRB, 2003), a traffic impact study (TIS) assesses the effect that a proposed development will have on the surrounding transportation network, the ability to get traffic on and off the site, and the need for off-site mitigation. A TIS is an essential part of the development review process to assist developers and public agencies in making land use decisions (Gluck and Lorenz, 2010). Most commonly traffic impact studies are associated with access permitting. A TIS, however, can be appropriate during any development activities where a proposal may have a substantial adverse impact on transportation operations. Gluck and Lorenz (2010) believe a well-prepared TIS helps the developer and permitting agency accomplish the following:

- Forecast the traffic impacts created by proposed development based on accepted practices, not perception
- Determine improvements needed to accommodate the proposed development
- Allocate funds more efficiently
- Relate land use decisions with traffic conditions
- Evaluate the number, location, and design of access points
- Update traffic data
- Identify needed roadway improvements

- Provide a basis for determining the developer’s responsibility for specific off-site improvements

Small developments (typically fewer than 100 trips per hour) usually are exempted from preparing a TIS, because the impact of these developments generally will be limited to the vicinity of the access connection. However, a site access and circulation review can be conducted to ensure that access connections are safely located. Principal elements of this review include sight distance, driveway geometry, driveway throat length, and provisions for bicycles and pedestrians (Gluck and Lorenz, 2010).

For all other developments (typically those that generate 100 trips or more in the peak hour), some type of traffic impact study generally is required as part of the access permit review application (ITE, 2006). The type of analysis can depend on the size, impact, and complexity of the development. Typically, the larger the development (as measured by the number of trips generated) the larger the area that may experience a measurable traffic impact caused by the development.

South Carolina’s DOT *2008 Access and Roadside Management Standards* requires traffic impact studies to be done for large developments such as major shopping centers, large planned-unit developments, industrial complexes, and other projects that would generate 100 or more trips during the peak hour of the traffic generator of the peak hour of the adjacent street (SCDOT, 2008). The SCDOT also includes a provision stating that if the district traffic engineer determines that the proposed development will have a significant impact at the proposed access points, even if the site generates fewer than 100 trips, to also require a TIS.

2.1.3 Condemnation/Eminent domain

Access control by the acquisition of property rights has been used on the Interstate Highway System since it was mandated by the Federal Aid Highway Act of 1956. A growing number of agencies are recognizing the benefits of acquiring property rights to control access on other important arterial highways to preserve safety and mobility (Gluck and Lorenz, 2010). The purchase of property rights can prevent undesirable accesses at the locations where the property rights were acquired (Huntington, D. and J. Wen, 2005).

The purchase of access rights may be expensive and time-consuming compared with access regulation, but the purchase of access rights is a stronger and longer-lasting solution. Regulations can change with political administrations and attitudes (Koepke and Levinson, 1992). Access rights may be purchased to achieve the following:

- Limit access to designated locations or side streets
- Control access and sight distance at intersections or interchanges
- Limit access to designated highways or new facilities and bypasses
- Introduce long-term or permanent access control
- Improve locations with high crash experience (TRB, 2003)

Access rights may be acquired through negotiation, purchase, or the power of eminent domain, and is recorded in the county of record. The purchase of access rights offers the following advantages:

- Provides long-term assurance of access control,
- Avoids concerns over property rights and regulatory takings by compensating property owners for access rights, and
- Avoids the expense of purchase or condemnation, if it is achieved through negotiated dedication.

The purchase of access rights may have the following disadvantages:

- Cost may be prohibitive,
- It may be difficult to establish a dedicated funding source in light of other needs,
- An effective tracking mechanism is required for enforcement, and
- Condemnation is required when a negotiated purchase is unsuccessful (TRB, 2003).

2.1.4 Zoning

Zoning regulates land use, density, lot size, building height, setback, yard characteristics, lot coverage, parking, signage, landscaping, and related issues. The text of the zoning ordinance includes standards for each of the above elements and is applied through various zones or districts for major categories of land use, such as residential, commercial, industrial, office, and agricultural. These zones are depicted on a zoning map. A zoning ordinance is a good place to include access management regulations. Many communities put all their access management standards in one section or part of the zoning ordinance. Typically when this is done, the access management standards apply to all lots on all roads and streets in the community. This helps identify all related standards for applicants and administrators. It also helps ensure consistency among the standards (as inconsistency is harder to spot when standards are scattered throughout the ordinance) (MDOT, 2001).

South Carolina Code of Laws, Title 6, Chapter 29, Article 5 covers legislation for municipalities and counties who establish zoning ordinances. This legislation specifically mentions that the zoning ordinance may include regulations related to curb cuts but does not mention specific access management standards required to be include as part of curb cut regulations. This is left up to the local jurisdiction.

2.1.5 Access Classification

An access classification system (ACS) typically is used to establish the level of allowable access for roadways of varying levels of importance in a state highway system (Gluck and Lorenz, 2010). As stated in the *Access Management Manual* (TRB, 2003), an ACS is a hierarchy of access categories that forms the basis for the application of access management. Although the structure of an ACS may vary widely among different agencies, establishing an ACS involves three basic actions according to Gluck and Lorenz (2010):

- Defining access management categories
- Establishing whether access should be permitted and related access spacing and design criteria for each category
- Assigning an access management category to each roadway or roadway segment

Each access category sets forth criteria governing the access-related standards and characteristics for corresponding roadways. These access categories define areas where access can be allowed between private developments and the roadway system, where it should be denied or discouraged, the spacing standards for signalized and unsignalized intersections, and where turning movements should be restricted. Defining access categories typically involves consideration of the following factors (Gluck and Lorenz, 2010):

- **Level of importance of the roadways within the overall network hierarchy**—The foundation of an ACS may be the functional classification system (i.e., arterial, collector, and so on) or another similar hierarchy that reflects the general purpose of each roadway within the transportation system.
- **Roadway characteristics**—Roadway characteristics associated with geometric design (e.g., number of lanes, design speed, and median treatment) and traffic operations (e.g., volume and speed) may be considered in defining access categories.
- **Degree of urbanization and land use controls**—Factors such as the intensity of existing and planned development, intersection frequency, parcel size, and need for a supporting circulation system can be used to help define the degree of urbanization and could be considered in defining access categories.

Direct property access is typically denied for higher-level arterial class roadways, and is often permitted for lower-level arterials and collectors. Direct property access may be provided for higher-level arterial class roadways when no reasonable alternative access is available. Direct property access typically is allowed on local roadways and frontage roads, subject to safety considerations, such as maintaining proper sight distances (Gluck and Lorenz, 2010).

The SCDOT currently classifies driveways according to the number of trips that will be generated by the land use that the driveway serves to help arrive at the appropriate design. The following table provides information regarding the classifications including land uses that might be expected to generate the specified volumes (SCDOT, 2008). The expected number of trips can be estimated using the latest edition of ITE's Trip Generation Manual.

Table 2.1 SCDOT Driveway Classification

Driveway Classification	Expected Trips	Example Land Use	Design Features
Low Volume	1-20 trips/day 1-5 trips/hour	Residential Drives (1-2 single family homes)	Typically designed with minimum requirements
Medium Volume	21-600 trips/day 6-60 trips/hour	Small subdivisions with single family homes or apartments, small business or specialty shop	Typically designed with some higher volume features such as radial returns.
High Volume	601-4,000 trips/day 61-400 trips/hour	Convenience store, gas stations, or small shopping center.	Typically designed with high volume such as radial returns and turn lanes.
Major Volume	>4,000 trips/day >400 trips/hour	Large shopping center or regional mall	Designed with high volume features including radial returns, turn lanes, and medians.

Source: 2008 Access and Roadside Management Standards (SCDOT, 2008)

As mentioned earlier, access classification systems (ACS) tend to vary among agencies. This variation is not only present among agencies in the US but worldwide. A review of access management practices in South Africa suggests that the AASHTO functional classification of access relative to mobility is not an accurate representation of roads in South Africa, especially in local applications (Stander and Watters, 2011). Being a second world country, South Africa has a unique mix of first and third world conditions. This makes the relationship between land use and access in majority of the areas in South Africa different from most areas in the US. Stander and Watters suggested that South Africa adopts Sampson's theory which is a modification of Brindle's theory. Brindle disagreed with traditional functional (hierarchical) road classification system described by AASHTO and postulated that there was a clear distinction between 'movement' routes and access routes (Stander and Watters, 2011). Sampson agreed with Brindle but made a modification to Brindle's theory, suggesting that the jump from mobility to access is not between collectors and local roads but between arterials and collectors (Stander and Watters, 2011). The authors of the study conclude that further research was needed to gain more clarity on the issue of road mobility and accessibility functions if South Africa was to adopt Sampson's theory and make modifications to access management manuals and guidelines.

2.1.6 Ranking of Required Features by Classification

For each roadway classification that is established, an agency must determine the access features that will be managed and how they will be managed. Access management standards for these features are assigned to roadways through the access categories (although access in the vicinity of interchanges typically is addressed through statewide standards, AMPs, or interchange areas management plans) (TRB, 2003). Access features to manage include the following:

- Traffic signals (minimum spacing or distances or through bandwidth)
- Driveway and street connections, and corner clearance (minimum spacing distances, location, allowable movements, and design)
- Medians (to manage left turns and direct access) and median openings (minimum spacing distances and design)
- Interchanges and access in the vicinity of interchanges

2.1.7 Legal Framework for Access Management

The feasibility of an access management program is determined by the ability of an authority to regulate access without having to compensate landowners (Urbitran, 2001). Two conflicting rights underlie this discussion: the public right to safe and efficient movement versus the landowners' right to suitable and sufficient access (Williams, Kristine M., and Forester, Richard J., 1996). When regulating access, governmental units attempt to balance public powers with private property rights.

2.1.7.1 The Protection of Property Rights

The legal basis for the protection of property rights is the taking clause in the U.S. Constitution and similar provisions in state constitutions. When the government takes property for public benefit, compensation is required. There are two general categories of takings: physical takings and regulatory takings (Skouras, 1998). Physical takings occur when the government actually takes or physically occupies the land for a public use. Regulatory takings occur when governmental regulations impose an inordinate burden on a specific piece of property, thereby depriving the owner of the use or enjoyment of that property (Kall et al., 2007). The standard for determining when a physical taking occurs is straightforward, but the standards for determining when a regulatory taking occurs are very complex.

2.1.7.2 The Right of Access is a Property Right

Throughout the United States, courts have held that a landowner whose property abuts a public highway possesses an easement of access to that highway. This right of access is subject to the constitutional right of just compensation when government action causes a loss of access (Kall et al., 2007). The vast majority of courts have held that total deprivation of access is equivalent to a compensable taking, particularly when the easement of access to the highway is recognized by state law. Even if the government does not totally deprive an abutting owner of all access, however, a substantial interference with the owner's right of reasonable access may nevertheless be a compensable taking of his property (Kall et al., 2007). In order to show substantial interference with access, it is sufficient if the landowner demonstrates that there has been a total temporary restriction or a partial permanent restriction of access. Most courts hold, however, that a compensable taking does not occur when the government merely regulates access, such as prohibiting left turns, specifying the location of driveways in and out of abutting property, or establishing one-way traffic (Kall et al., 2007). Thus, the government can reasonably regulate a property owner's right of access, but it cannot deny that right without the payment of just compensation.

2.2 Access Management Features

2.2.1 Crash Modification Factors

A crash modification factor (CMF) is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site. CMF's in this report will be presented in a format listing both the countermeasure and CMF number or function associated with the countermeasure. Refer to Appendix for full references for crash modification factors.

2.2.2 Intersections and Driveways

2.2.2.1 Spacing & Signal Density

Establishing traffic signal spacing criteria for arterial roadways is one of the most important and basic access management techniques. The same criteria for signal spacing apply to both signalized driveways and signalized public roadway intersections.

The spacing of traffic signals, in terms of frequency and uniformity, governs the performance of urban and suburban highways. Traffic signals account for most of the delays that motorists experience. Closely or irregularly spaced signals reduce arterial travel speeds, thereby resulting in an excessive number of stops even under moderate traffic volume conditions. Signals also can increase crash frequency (Gluck, Levinson, and Stover, 1999). Xu et al. (2011) investigated the impact of access management techniques on crash counts at signalized intersections in Southern

Nevada. The results showed that the average length of corner clearance had negative impact on intersection crash occurrence while the total traffic flow in all directions, land use types, the number of lanes for minor streets and posted speed limit on minor streets were positively related to crashes at signalized intersections.

Central and Eastern Europe experience as much as 80 driveways per kilometer in suburban areas which reduces driving speed during peak hours due to merging of through traffic and driveway traffic. There is no specific legislation focused on access management in all over Greece (Tracz et al., 2011). A South African province published "Road Access Guideline (RAG) "in 1996 and recommended to consider a driveway as an intersection depending on the driveway traffic volume (Watters et al., 2011). RAG also recommends signalized intersections should be spaced such that mainline progression bandwidth get minimum disturbance. In case of unsignalized intersections, traffic delays, nearby driveway location, stopping sight distance, left turn conflicts, and signage should be considered (Watters et al., 2011).

2.2.2.1.1 Crash Modification Factors

Countermeasure	CMF
Change in Signal Spacing from X 1000's feet to Y 1000's feet	$e^{-0.1276(Y-X)}$
Change the Natural Log of the Downstream Distance to the Nearest Signalized Intersection for an Unsignalized 3-leg Intersection from X to Y	$e^{-0.0345(Y-X)}$
Change the Natural Log of the Downstream Distance to the Nearest Signalized Intersection for an Unsignalized 4-leg Intersection from X to Y	$e^{-0.4815(Y-X)}$
Where Y = Signal spacing in post condition X = Signal spacing in pre-condition	

2.2.2.1.2 State Research

Certain states have performed studies explaining why they use certain signal spacing and how they are different from other states' signal spacing.

2.2.2.1.2.1 Minnesota

MnDOT wanted to determine the optimal balance between two groups of customers that travel through urban arterials. One group was identified as having the desire to travel as fast as possible without excessive speed reductions and signal delays while the other was characterized as the local-trip drives that need to cross or travel on a segment of the highway to get home and to work. MnDOT decided to simulate 1 mile, ½ mile, and ¼ mile intersection spacing help find the optimal balance and the mobility benefits of signal progression on the main roads with overall network travel time and delays. Based on the simulations, MnDOT explains that the spacing for signals and the need to achieve signal progression is direction related to the spacing of primary, full-movement intersections. MnDOT claim that because major intersections are most likely signalized intersections, the signalized intersections need to be spaced uniformly to help the movement of large groups of traffic. This helps with traffic in both directions enabling the traffic to travel at a uniform speed not needing to stop at each signal. The results the Mn/DOT found and currently use illustrated in Figure 2.1 and Figure 2.2.

Figure 2.1: Recommended Street Spacing for IRCs

Category	Area or Facility Type	Typical Functional Class	Public Street Spacing: Primary Full-Movement Intersection	Public Street Spacing: Secondary Intersection	Signal Spacing
1	High-Priority Interregional Corridors & Interstate System (IRCs)				
1F	Interstate Freeway		Interchange Access Only		⊘
1AF	Non-Interstate Freeway		Interchange Access Only (see Section 3.2.7 for interim spacing)		
1A	Rural	Principal Arterials	1 mile	1/2 mile	See Section 3.2.5 for Signalization on Interregional Corridors
1B	Urban/ Urbanizing		1/2 mile	1/4 mile	
1C	Urban Core		300-660 feet dependent upon block length		
2	Medium-Priority Interregional Corridors				
2AF	Non-Interstate Freeway		Interchange Access Only (see Section 3.2.7 for interim spacing)		See Section 3.2.5 for Signalization on Interregional Corridors
2A	Rural	Principal Arterials	1 mile	1/2 mile	
2B	Urban/ Urbanizing		1/2 mile	1/4 mile	
2C	Urban Core		300-660 feet, dependent upon block length		1/4 mile
3	Regional Corridors				
3AF	Non-Interstate Freeway		Interchange Access Only (see Section 3.2.7 for interim spacing)		Interim
3A	Rural	Principal and Minor Arterials	1 mile	1/2 mile	See Section 3.2.5
3B	Urban/ Urbanizing		1/2 mile	1/4 mile	1/2 mile
3C	Urban Core		300-660 feet, dependent upon block length		1/4 mile

Figure 2.2: Recommended Street Spacing for Non-IRCs

Category	Area or Facility Type	Typical Functional Class	Public Street Spacing: Primary Full-Movement Intersection	Public Street Spacing: Secondary Intersection	Signal Spacing
4	Principal Arterials in the Twin Cities Metropolitan Area and Primary Regional Trade Centers (Non-IRCs)				
4AF	Non-Interstate Freeway	Principal Arterials	Interchange Access Only (see Section 3.2.7 for interim spacing)		Interim
4A	Rural		1 mile	1/2 mile	See Section 3.25
4B	Urban/ Urbanizing		1/2 mile	1/4 mile	1/2 mile
4C	Urban Core		300-660 feet, dependent upon block length		1/4 mile
5	Minor Arterials				
5A	Rural	Minor Arterials	1/2 mile	1/4 mile	See Section 3.25
5B	Urban/ Urbanizing		1/4 mile	1/8 mile	1/4 mile
5C	Urban Core		300-660 feet, dependent upon block length		1/4 mile
6	Collectors				
6A	Rural	Collectors	1/2 mile	1/4 mile	See Section 3.25
6B	Urban/ Urbanizing		1/8 mile	Not Applicable	1/4 mile
6C	Urban Core		300-660 feet, dependent upon block length		1/8 mile
7	Specific Area Access Management Plans				
7	All	All	By adopted plan		

2.2.2.1.2.2 *Oregon*

Oregon uses a different technique of signal spacing by characterizing it in cycle length. The ODOT claims that the optimal spacing of signals is dependent on the speed, cycle length, traffic volumes, and efficiency of signal progression. In urban major arterials with speeds of 30 to 45 mph, the typical values for cycle lengths are 120 to 150 seconds. For suburban arterials with speeds of 40 to 50 mph, the usual cycle length is 90 seconds, and for rural arterials speeds of 45 to 55 mph, the cycle lengths are 60 seconds.

2.2.2.1.2.3 *Texas*

Texas has performed studies and found that each traffic signal per mile reduces the travel speed of around 2 to 3 mph. The information that the TxDOT found and recognizes is illustrated in Table 2.2.

Table 2.2 Travel Time and Signal Density

Percentage Increase in Travel Times as Signalized Density Increases	
Signals Per Mile	Percent Increase in Travel Times (Compared with 2 Signals Per Mile)
2.0	0
3.0	9
4.0	16
5.0	23
6.0	29
7.0	34
8.0	39

2.2.2.2 Driveways within Influence Areas

Access points, commonly referred to as driveways or street connections, introduce conflicts and friction into the traffic stream. They are, in effect, intersections and should be designed consistent with their intended use (Gluck and Lorenz, 2010). *A Policy on Geometric Design of Highways and Streets* indicates that the number of crashes is disproportionately higher at driveways than at other intersections. Therefore, driveway design and location merit special consideration (AASHTO, 2004).

Roadways with properly managed access have lower crash rates than other roadways (Gluck and Lorenz, 2010). Arterial roadways with many driveways and signals often have double or triple the crash rates of roadways with wide spacing between access points or of roadways where access is fully controlled. Crash rates generally increase with greater frequencies of intersections and driveways (Gluck and Lorenz, 2010).

2.2.2.2.1 Crash Modification Factors

Countermeasure	CMF
Absence of Access Points	0.56
Change Driveway Density from X to Y Driveways per Mile	$e^{0.0152(Y-X)}$
Change Driveway Density from X to Y (driveways/mile for segment)	$e^{0.0232(Y-X)}$
Change Driveway Density from X to Y Driveways per Mile	$e^{0.0096(Y-X)}$
Where Y = # of driveways per mile in post condition X = # of driveways per mile in pre condition	

2.2.2.2.2 State Research

2.2.2.2.2.1 *Texas*

Texas also performed studies on how the number of access points affects the free flow of speed. The fewer access points on a road the more efficiently traffic moves, which reduces fuel consumption and vehicle emissions. The results found are illustrated in Table 2.3.

Table 2.3 Access Points and Flow

Access Points and Free Flow Speed	
Access points per mile	**Reduction in free flow speed, mph**
0	0.0
10	2.5
20	5.0
30	7.5
40 or more	10

2.2.2.3 U-turns

In some cases, U-turn design can be used as a technique of access management. Potts et al. (2004), presented a classification scheme for median openings, summarized the results of comprehensive field studies, and identified several highway planning implications. The research results indicated that increasing U-turn volumes at unsignalized median openings can be used safely and effectively. Analysis of crash data found that crashes related to U-turn and left-turn maneuvers at unsignalized median openings occur very infrequently.

2.2.2.4 Roundabouts

Besides signal controls, roundabouts were also mentioned as a technique in access management to improve traffic safety and operations. Johnson and Isebrands (2008) analyzed benefits of roundabouts and their effects on traffic operations and safety. They also addressed business access into and near roundabouts, roundabouts in series, and other access management issues compatible with roundabouts in redevelopment, new development, and urban constrained environments. Authors concluded that roundabouts can provide flexibility for accesses at and near intersections as well as along a corridor. Furthermore, roundabouts offer the ability to meet the safety, capacity, and operational objectives of a roadway while also providing access and site circulation opportunities not typically available with signalization.

2.2.3 Midblock

2.2.3.1 Median Treatments

Median treatments for roadways represent one of the most effective means to regulate access, but are also the most controversial. The two major median treatments include two-way left turn lanes (TWLTL) and raised medians (FHWA, 2013). According to an analysis of crash data in seven states, raised medians reduce crashes by over 40 percent in urban areas and over 60 percent in rural areas (Gluck, Levinson, and Stover, 1999) A study of corridors in several cities in Iowa found that two-way left-turn lanes reduced crashes by as much as 70 percent, improved level of service by one full grade in some areas, and increased lane capacity by as much as 36 percent (IOWADOT, 1997). Raised medians also provide extra protection for pedestrians. A study of median treatments in Georgia found that raised medians reduced pedestrian-involved crashes by 45 percent and fatalities by 78 percent, compared to two-way left-turn lanes (TTI, 1994).

2.2.3.1.1 State Research

Medians have extremely high safety factors that has been proven in studies performed by state DOTs.

2.2.3.1.1.1 *Utah*

UDOT did a study of their own finding out the safety factors of raised medians. UDOT found out that raised medians reduced the frequency of crashes by 39% and reduced the frequency of severe crashes by 44%.

2.2.3.1.1.2 *Mississippi*

MDOT identifies in their Access Management Guide a median policy presenting three benefits that medians include along with illustrations of four major types of raised restrictive medians. The three benefits shown are safety, vehicular efficiency, and aesthetics. MDOT claims that raised medians are an efficient way to reduce crashes and should be a strong consideration of being used where not being used.

2.2.3.1.1.3 *Texas*

TxDOT has collected data of crash rates that have occurred at different types of medians provided a sufficient amount of information on the different types of medians and their safety factor. The data collected is illustrated in Table 2.4.

Table 2.4 Crash Rates by Median Type

Representative Crash Rates (Crashes per Million VMT) by Type of Median – Urban and Suburban Areas			
Total Access Points per Mile (1)	Median Type		
	Undivided	Two-Way Left-Turn Lane	Non Traversable Median
<20	3.8	3.4	2.9
20.01 – 40	7.3	5.9	5.1
40.01 – 60	9.4	7.9	6.8
>60	10.6	9.2	8.2
Average Rate	9.0	6.9	5.6

*Includes unsignalized and signalized access points

2.2.3.1.2 Traversable
2.2.3.1.2.1 TWLTL

Exclusive turning lanes for vehicles remove stopped vehicles from through traffic. Left-turn lanes at intersections substantially reduce rear-end crashes (FWHA, 2013). Research conducted by Gluck, Levinson, and Stover (1999) on left-turn lanes demonstrated that exclusive turn lanes reduce crashes between 18 to 77 percent (50 percent average) and reduce rear-end collisions between 60 and 88 percent. Left-turn lanes also substantially increase the capacity of many roadways. A shared left-turn and through lane has about 40 to 60 percent the capacity of a standard through lane (Gluck, Levinson, and Stover, 1999).

Adding center lane is the most popular and economic treatment type in Poland to improve traffic operation and safety on two lane suburban areas. Service drive is preferred option to get best performance along main corridor, and TWLTL could be considered when enough right of way is not available for service drive (Tracz et al., 2011).

2.2.3.1.2.1.1 Crash Modification Factors

Countermeasure	**CMF**
Add Two-Way-Left-Turn-Lane (TWLTL) to the Major Approach of an Unsignalized 3-leg Intersection	0.69
Add Two-Way-Left-Turn-Lane (TWLTL) to the Major Approach of an Unsignalized 4-leg Intersection	0.66
Convert an Open Median to a TWLTL	1.45

2.2.3.1.3 Non-Traversable

Non-traversable medians are usually used as a key technique in access management. Gattis and Hutchison (2000) made a comparison of three urban arterial roadways in Springfield, Missouri The three urban arterial roadways had similar lengths, posted speed limits, volumes, and abutting land uses but different levels of access control. They found that the roadway section with a non-traversable median and greater access spacing had a lower crash rate and less delay than others with a two-way left-turn lane. A comparison of the two two-way left-turn lane roadways found that an increase in driveway spacing did not produce faster travel times or a lower crash rate.

2.2.3.1.3.1 Raised Median

Roadways with raised median usually have lower crash rates than roadways with no median, two-way left-turn lane or other types of medians. Gattis et al. (2010) developed relationships between crash rates and different types of medians categorized into roadways with no median, roadways with occasional left-turn lanes, roadways with continuous two-way left turn-lanes, and roadways with raised or depressed medians. They concluded that the raised or depressed medians generally had lower crash rates than the other types of medians. Similarity, Mauga and Kaseko (2010) evaluated and quantified the impact of types of medians, including raised medians and two-way-left-turn-lanes, and other access management attributes on traffic safety in the midblock sections. The results showed that segments with a raised median had lowered the crash rate by 23% compared to segments with a two-way left-turn lane. The higher densities of driveways and median openings resulted in higher crash rates and severity.

2.2.3.1.3.1.1 Crash Modification Factors

Countermeasure	CMF
Install Raised Median	0.61
Replace TWLTL with Raised Median	0.77

2.2.3.2 Turning Radii

The turning radius of a driveway or access road affects both the flow and safety of through traffic as well as vehicles entering and exiting the roadway. The size of the turning radius affects the speed at which vehicles can exit the flow of traffic and enter a driveway. In general, the larger the turning radius, the greater the speed at which a vehicle can turn into a site (Nashua, 2002). An excessively small turning radius will require a turning vehicle to slow down significantly to make the turn, therefore backing up the traffic flow or encroaching into the other lane. An excessively large turning radius will encourage turning vehicles to travel quickly, thereby creating hazards to pedestrians (Nashua, 2002). Either of these situations increases the potential for collisions. The speed of the roadway, the anticipated type and volume of the traffic, pedestrian safety and the type of use proposed for the site should be considered when evaluating the turning radius (Nashua, 2002). Proposed uses that would require deliveries by large trucks (such as major retail establishments and gas stations) should provide larger turning radii to accommodate such vehicles. Other uses such as banks, offices or areas with high pedestrian traffic could adequately be served with smaller turning radii based on the type of traffic they would generate.

2.2.3.3 Right-in/Right-out driveways

Another common access management technique in use is the use of right-in/right-out (RIRO) driveways. RIRO driveways are designed to dissuade a driver from making left turns to or from the adjacent street. RIRO driveways generally consist of a raised curbed or solid concrete island and regulatory signage (“No Left Turn” signs). Placing “No Left Turn” regulatory signs makes the movement illegal and enforceable (USDOT, 2001). The use of RIRO driveways is discretionary based on local codes and policies, alternate available access, and the specific site layout. The purpose for dissuading left turns is to reduce vehicular conflict points, which are directly related to traffic crashes and delay (Thieken and Croft, 2003).

Assuming compliance, a right-in/right-out (RIRO) driveway reduces the conflicts from 9 to 2 by eliminating left-in (LI) and left-out (LO) movements (Thieken and Croft, 2003). The three crossing conflict points that are eliminated are likely the most critical with respect to crash severity (Thieken and Croft, 2003). The majority of crashes at driveways involve left turning vehicles. Thus, eliminating left-turn movements should significantly reduce the potential for crashes (Thieken and Croft, 2003). The primary issue with RIRO driveways is that compliance is necessary to realize the reduction in conflict points.

2.3 Operational Impacts

Operational impacts of access management vary with type of access control strategies. NCHRP report 500 complied operational impacts of different access control at signalized intersection. It concluded that increasing access point density reduced vehicle operating speed because of speed differential between driveway and mainline vehicles and increased rear-end crashes. Relocating or closing driveway close to intersections or limiting turning movements was recommended to improve the traffic operation at intersections (Antonucci et al., 2004). Similar to the impacts of access point, operational efficiency along corridor was reduced with increasing signal density as signals created more conflict points, and increased crash rates (Gluck et al., 1999; TRB, 2003).

A Florida study examined the impact of access points on operating speed, and found that average speed could be reduced as much as 5 to 10 mph due to inappropriate location, design and spacing of driveways (McShane, 1996). Besides traffic operational improvement, reducing access point density could create visually appealing landscape and livability of location, and could improve roadway capacity and reduce need of new capacity improvement (TRB, 2003). Beside, access management improved traffic flow by reducing delay and increasing operating speed along the corridors, and reduced emission and save fuel consumption (TRB, 2003).

Washburn and Kondyli (2006) developed quantitative tools and guidance for the location of signalized intersections near interchanges. The tool has two features, including an assessment of the adequacy of a given signal spacing and an estimate of the average travel speed between the interchange off-ramp and first downstream signal. The research findings indicated that a minimum signal distance of ¼ mile is sufficient for a range of conditions considering arterial speeds and progression quality; however, more restrictive guidelines of ½ mile should be applied in cases where the anticipated development will reach high levels.

Selecting appropriate access control strategies must consider site specific geometric conditions, and mainline and driveway traffic volume (Chowdhury et al., 2005). Chowdhury et al. developed simulation models to examine the operational impacts of different access control strategies under various traffic scenarios. This study reported that concentrated left turns performed better than direct left turn from driveway, and right-of-way restriction to provide U-turn, and mid-block opening on divided multilane highways could be solved by Jughandle design. Guo et al. (2011) developed a negative-binomial model to estimate the number of U-turning vehicles on a left-turn approach at a signalized intersection during peak periods. They concluded that providing U-turns at signalized intersections will inevitably have some negative impacts on the capacity and level of service of signalized intersections because of the increased traffic demand and reduced saturation flow rate. However, Lu et al. (2005) concluded that U-turns at signalized intersection could have better operational performance than direct left turns under certain traffic and roadway geometric conditions. Dissanayake and Lu (2003) analyzed both operational and safety characteristics of a full median opening and those of a directional median opening, in the form of a before-and-after study. According to the findings, the total weighted average travel delay was significantly reduced after the median opening was made to function as directional.

Looking at international perspective of access control, one Greek study concluded that all Greek cities experience congestion, travel delay due to poor or no proper access management practices (Maratou et al., 2011). An European study found that residential driveways do not impact the mainline travel speed much while business driveways with more than 60 veh/h have significant impact on mainline travel speed on two lane highways (Tracz et al., 2011). Unplanned access design in Greece increased safety concerns in most cities as well as created unreasonable travel delay (Maratou et al., 2011)

Koklas et al wrote on access and congestion management strategies used at peak hours during the construction of the ‘Korinthos-Patra’ (KOPA) section of Olympia Odos; an interurban road section in Greece. Due to reduced capacity as a result of the ongoing construction there were excessive delays on the KOPA section especially at the two toll stations in either direction. The most unusual among the strategies used was to suspend toll collection for 15 minute periods during peak hours when the delays exceeded 30-40 minutes. This allowed approximately 650-700 vehicles to pass relieving upstream traffic (Koklas et al, 2011).

Another special case of access management in Greece was during the 2004 olympic games. The Attica Tollway, constructed a few months before the Olympic games was used as the main access to most of the Olympic venues The Attica tollway is one of the largest co-financed road projects in Greece and Europe (Halkias et al, 2008). This 70 km ring road connected 30 municipalities in Athens and run through the Olympic village (Halkias et al, 2008). An agreement was reached between the Attica Tollway Operation Authority and the Athens Olympic committee (ATHOC) to allow the Olympic family vehicles including the bus fleet to use the electronic toll collection (ETC) lanes which were typically closed to buses. This provided efficient traffic movement throughout the games (Halkias et al, 2008). Aside the tollway agreement an Olympic road network (ORN) was created on existing roadways where only tagged vehicles were authorized to use (Halkias et al, 2008). These measures, as well as other congestion management strategies helped to provide efficient movement of traffic throughout the games.

2.4 Economic Impacts

While appropriate access management strategies for new developments might not have any strong reactions from developers, any changes to existing access control along a corridor or isolated location receive intense attention from nearby business owners. Usually initial reactions are against access modifications, but these perceptions evolve along with time. In a Kansas Study, researcher studied fifteen businesses that sued Kansas Department of Transportation, and concludes that if new strategies did not require extreme circulation, business did not experience any negative impacts, and some business had positive growth (Rees et al., 2000). Still, transportation agencies frequently getting sued for new access control initiatives along existing developments, and courts often order to provide compensation based on the merit of claim, especially for corner gas stations (Bainbridge, 2010).

Expected economic impacts of access management strategies depend on the type of strategies. A NCHRP report concluded that left turn restrictions had mix-perception from businesses. Some businesses suspected of negative impacts where others saw improvement in congestion and traffic flow corridor (Weisbrod, and Neuwirth, 1998). On the other hand, motorists had favorable view about access control projects, and reported access improvement make the corridor safer (City of Renton, 2005; FDOT, 2012).

Impacts of access control are also varied by type of business. Customers plan ahead of trip to visit “Destination business” such as electronic store, salon, while customers do not plan ahead of trip to visit “Drive- by business” such as gas station, convenience store (FHWA, 2006). In general destination business had much favorable view regarding access management compared to drive- by business. However, access control was not the sole factor contributes to success or failure of a business (FHWA, 2006). A Texas study reported that gas stations (drive-by business) had experienced sales drop due to restriction in direct left turn, while auto repair shops (destination business) saw more business. Most of the business owner perceived quality of product, and service were more important than type of access (Eisele and Frawley, 1999). Similar findings were reported in a survey study among business owners in Western Washington (Vu et al., 2002).

There is also general believe of property devaluation due to access management projects. Despite negative perception, a Texas study examined change in property value due to access improvement projects, and did not find any devaluation of properties along the corridors after such projects (Eisele and Frawley, 1999). A Minnesota study examined the impact of changing a corridor to full access controlled freeway facility, and before and after study revealed that traffic flow along the corridor significantly increased and new businesses were attracted to the corridor. This study concluded that property value was mostly depended on the local economy irrespective of access control to the properties (Plazak, and Preston, 2005). So, there were big different in perception and reality about the effects of access control (Eisele and Frawley, 1999; Plazak and Preston, 2005). Similarly, another access management study in Kansas did not observe any negative change in abutting business demand after limiting direct access except one drive-by business (Rees et al., 2000).

As most of the studies looked at before and after scenario of access management projects, a Washington study surveyed 280 businesses along six corridors in Western Washington to understand the business concerns and impacts of different access management strategies. This survey revealed that businesses perceived right-in-right-out as the most severe form of access restriction among all access management strategies. However, most business types did not see any major impact of access control strategies (Vu et al., 2002).

2.5 DOT Best Management Practices

2.5.1 Summary of DOT Practices

Seventy-one percent of 45 state DOTs that were including in a survey indicated that changes are needed to make their programs more effective. Some of the state DOTs identified that their program needs to be reviewed and updated periodically, needs to have less political influence, and needs to be more consistent and less subject to interpretation. States all around the country have unique ways to make their manuals more efficient and comprehendible by using graphs and databases. State DOTs have performed studies showing how to reduce crashes making roads safer for the public and improve access management enhancing public transportation.

2.5.1.1 ***Arkansas, Montana, and Nebraska***

Arkansas, Montana, and Nebraska’s Access Management Manual is short and brief. The manual gives brief definitions and provides only some tables, illustrations and guidelines.

2.5.1.2 ***California***

California DOT (Caltrans) uses an unusual formula to determine the maximum amount of driveway width allowed for a commercial property. When more than one driveway is to serve a property, the width of all driveways should not exceed 70% of the frontage when the frontage is 100 feet or less and should not exceed 60% of the frontage when the frontage is greater than 100 feet.

Caltrans uses certain equations to define the equitable share responsibilty in projects within the state of California. This method of calculating the equitable share of mitigation cost for propsed projects has been in effect since December of 2002. The method consist of 3 equations:

- Equation 1 – Equitable Share Responsibility
- Equaiton 2 - Equitable Cost
- Equation 3 – Proportionality

$P = T/(T_B-T_E)$ (1)

P = The equitable share for the proposed project's traffic impact

T = The vehicle trips generated by the project during the peak hour of adjacent state highway facility in vehicles per hour (vph).

T_B = The forecasted traffic volume on an impacted state highway facility at the time of general plan build-out, vph.

T_E = The traffic volume existing on the impacted state highway facility plus other approved projects that will generate traffic that has yet to be constructed or opened, vph.

$C = P(C_T)$ (2)

C = The Equitable cost of traffic mitigation for the proposed project.

P = The equitable share for the project being considered (from Equation 1).

C_T = The total cost estimate for improvements necessary to mitigate the forecasted traffic demand on the affected state highway facility in question at general plan build-out ($).

$C = P(CT-C_C)$ (3)

C = Same as Equation 2

P = Same as Equation 2

C_T = Same as Equation 2

C_C = The combined dollar contributions paid and committed before the current project's contribution (necessary to provide the cost proportionality).

2.5.1.3 ***Colorado***

CDOT's State Highway Access Code states clearly "when the land use generates a design hour volume (DHV) of 100 vehicles or more, or when considered necessary or desirable by the issuing authority or Department for exceptional reasons, the applicant shall provide a traffic impact study."

Construction of the access shall not proceed until both the access permit and the Notice to Proceed are issued. The Notice to Proceed is not a license. It states that the permittee has met the pre-construction and permit submittal requirements and may now proceed with construction. When ready to begin construction, the applicant must submit all permit required construction drawings, specifications and other required items, along with a copy of the access permit to the issuing authority and provide a copy to the Department if the Department is not the issuing authority.

The permittee or contractor may be required to provide comprehensive general liability and property damage insurance naming the Department and the issuing authority (if applicable) as an additional insured party in the amounts of not less than $600,000 per occurrence and automobile liability insurance of $600,000 combined single limit bodily injury and property damage for each collision, during the period of access construction.

2.5.1.4 ***Idaho***

ITD has unique guidelines when considering Left-Turn Lanes and Right-Turn Lanes. Installing a Left-Turn Lane should be considered when there has been an average of 4 crashes per year over a five-year period at an existing approach without turn lanes. The same guidelines are followed for installing a Right-Turn Lane. The safety factors and the control medians offer to the state of Idaho, the DOT strongly considers the use of medians for:

- All new multi-lane States highways
- Modernization of all multi-lane State highways where posted speeds are 45 mph or greater
- All undivided State highways where the annual collision rate is greater than the statewide annual average collision rate for similar roadways
- All State highways when the average daily traffic (ADT) exceeds 28,000 vehicles per day in both directions
- All multi-lane State highways undergoing resurfacing, restoration, and rehabilitation improvements

2.5.1.5 ***Iowa***

Iowa DOT uses a method called Access Rights to provide the most efficiency of traffic movement desired. Access Rights prohibits direct access to the primary highway, increasing the free and efficient movement of through traffic and making the roads more safe minimizing the number of entrances along the highway. In a rural area, the minimum distance from the intersection of the centerlines of two highways is illustrated below in Table 2.5.

Table 2.5 Vehicles per day vs. Minimum Distance from the Intersection Centerlines

Vehicles per day	Minimum Distance from the Intersection Centerlines (Feet)
<2,500	150
>2,500	300

2.5.1.6 ***Kansas***

KDOT has six access types that are based on daily traffic volumes and property use. Access type is an important component of the permitting process and helps KDOT to determine where to best locate an access and what design criteria apply. The list of access types is shown in Table 2.6.

Table 2.6 Access Types

Type	Traffic Volume	Use
1	Low volume 0–49 vehicles per day maximum, in/out bound traffic count	Non-commercial—farm, agriculture, field, timber, cultivated, pasture, duplex, single family residential/home, apartment building containing five or fewer dwelling units, other
2	Low volume 0–49 vehicles per day maximum, in/out bound traffic count	Special-use—city water treatment plant, microwave station, pipeline checkpoint, telephone repeater stations, utilities (electric, gas, telephone, and water) check/ maintenance stations, Corps of Engineers dike roads, other
3	Low volume 0–49 vehicles per day maximum, in/out bound traffic count	Emergency facility—fire station, paramedic facility
4	Low volume 0–49 vehicles per day maximum, in/out bound traffic count	Commercial—small business, cemetery, nursing home, other
5	Medium volume 50–499 vehicles per day and less than 50 vehicles per peak hour of the highway (in/out bound traffic count)	Commercial, industrial, institutional, recreational, local road connections, including shared access, other
6	High volume 500 or more vehicles per day or 50 or more vehicles per peak hour of the highway (in/out bound traffic count)	Commercial, industrial, institutional, recreational, local road connections, including shared access, other

KDOT requires all applicants to complete the Application for Highway Access. The Application for Highway Access may be obtained at any of KDOT's 26 Area offices. In addition, an electronic version of the application is posted on KDOT's website. The Area office reviews the application and coordinates with the applicant as needed to compile any necessary supporting documentation. The supporting documentation is described in Table 2.7.

Table 2.7 Supporting documentation for Application for Highway Access by access type

Access Type	Application	TIS		Drainage Report	Site Plan	Plans for Construction	Environmental Considerations
		Basic	Compre-hensive				
1	●			▲			●
2	●			▲			●
3	●			▲	▲	▲	●
4	●	▲		▲	▲	▲	●
5	●	●	▲	▲	●	▲	●
6	●		●	▲	●	●	●

▲ Determined by KDOT on a case-by-case basis
● Always required

In 2A-2. Preliminary Site Plan and Traffic Impact Study Review, page 14, ARMS Manual, it states that "In cases such as large developments (e.g. industrial parks, shopping centers, large apartment complexes, or school sites) where significant traffic volumes are expected, considerable time and effort often can be saved and the permitting time shortened when the Department and the local jurisdiction are involved in the early stages of development planning. In such cases, the Department recommends a preliminary site development plan and traffic impact study (TIS) be submitted before the permitting process is begun." It is not clear from the SCDOT's ARMS manual how volumes are considered to warrant a TIS. In contrast, KDOT's Access Management Policy clearly specifies whether a basic TIS or a comprehensive TIS is needed based on the specific conditions involved with the request for access. Table 2.8 lists the TIS requirements for access types 4, 5, and 6. Further, KDOT's Access Management Policy describes the requirements for receiving a Highway Access Permit, including fees and insurance requirements.

Table 2.8 TIS required by access type

Access Type	Volume	Trip Generation (trips/day)	Land Use Description	Basic TIS	Comprehensive TIS
4	Low	0–49	Commercial—small business, cemetery, nursing home, other	▲	
5	Medium	50–499	Commercial—industrial, institutional, recreational, local road	●	▲
6	High	500 and over	Commercial—industrial, institutional, recreational, local road		●

▲ Determined by KDOT on a case-by-case basis
● Always required

2.5.1.7 ***Louisiana***

La DOTD categorizes sight distance into 4 categories. The four categories of sight distance are stopping sight distance (the distance required for a vehicle to stop on any type of highway), passing sight distance (the distance required to pass a vehicle on two-lane highways), decision sight distance (the distance needed to make decisions at information sources or hazards), and Intersection sight distance (the distance provided when feasible at intersections to enhance the safety of the facility). La DOTD also describes in detail the different types of curbs at driveways, breaking them up into four categories including mountable curbs, barrier curbs, curbed driveways, and curbed islands.

2.5.1.8 ***Minnesota***

MnDOT Access Management Manual identifies the importance of key factors in the development review and permitting process. One key factor the manual highlights is the idea of access should be one of the first factors addressed. While sites are considered for development, one should look at the site that offers the best access. Another key factor highlighted by the manual is to prioritize efforts. MnDOT concentrates more on access that has the greatest potential to affect highway safety and mobility and concentrates less on low-volume access, giving a more routine evaluation. MnDOT also recommends a certain sight distance for each access type (illustrated in Table 2.9) and also describe alternatives if corner clearances cannot be met.

Table 2.9 Sight Distance Based on Access Type

Access Type		Recommended Sight Distance
1	Residential/Field Entrance	Decision Sight Distance
2	Low-volume Commercial	Decision Sight Distance
3	High-volume Commercial	Intersection Sight Distance
4	Public Intersections	Intersection Sight Distance

*****Decision Sight Distance- also known as the Ten-Second Decision Sight Distance, allows a driver adequate time to react to a situation on the highway and maneuver, whether to stop or change lanes.

When the corner clearance cannot be met, MnDOT follows the following guidelines to minimize the impacts:

- The driveway should be located as far as possible on the parcel or lot from the intersection. A shared driveway with an adjacent parcel should be used to provide even greater clearance from the intersection
- If a single driveway is being provided to a corner parcel, the driveway should be located on the cross street; and,
- A median may be installed on the approach legs to an intersection, or the driveway may be designed to prevent left-turn movements from crossing turn lanes.

2.5.1.9 ***Missouri***

MoDOT believes raised medians are the most effective tool for access management on high-volume roads. The Access Management Guidelines recommend that raised medians be used on every urban road where the current and projected AADT is greater than 28,000. Missouri also uses the number of commercial driveways per mile to determine whether or not to use raised medians. In situations where other access management strategies such as driveway consolidation are not practical the Missouri DOT recommends that raised medians be used on every road where there are more than 24 commercial driveways per mile in both directions.

2.5.1.10 ***Nevada***

NDOT has 8 access category standards that are explained thoroughly in the access management manual for Nevada. The manual goes into deep detail about each category explaining the functional characteristics and design standard for each. The categories are Freeways, Expressways, Regional Highways, Rural Highways, Principal Arterials, Minor Arterials, Collectors, and Frontage or Service Roads.

2.5.1.11 ***New Mexico***

NMDOT splits the spacing of Unsignalized Access in to two different categories, Full Access and Partial Access. The spacing of Unsignalized Access for Full Access and Partial Access is different in each access category in the NDOT. Both categories that fall under Unsignalized Access are very detailed and explain each guideline for Full Access and Partial Access under each certain access category.

2.5.1.12 ***North Dakota***

NDDOT determines specific location of individual access points by determining a joint effort between the Design Division, District, Planning and Programming, and representatives of the local agency. Changes to the size, location, and number of access points on a property will only be made with mutual consent of all involved parties.

2.5.1.13 ***Oregon***

ODOT has been using a database called CHAMPS (Central Highway Approach/Maintenance Permit System), which allows application and permit records and processes used by the permit specialist to be consistently managed. CHAMPS is a statewide database allowing permit specialist to access it anywhere in the state. Every single driveway connecting to the state highway system is recorded and tracked in CHAMPS. The use of CHAMPS by the ODOT enhances the permit application, review, and approval process assisting permit specialists in daily organization and management of these criteria. There are many features and advantages that CHAMPS holds for the ODOT, allowing permit specialists to do the following:

- Initiate, deny, or void new access permit applications
- Open, view, update, and save existing “in-process” permit applications
- Identify and update permit review and approval status
- Record the results of field inspections
- Amend or cancel existing permits
- Generate formal letters for typical access-related actions using standardized templates
- Issue new permits to applicants

Two examples of the CHAMPS windows are illustrated in Figure 2.3 and Figure 2.4.

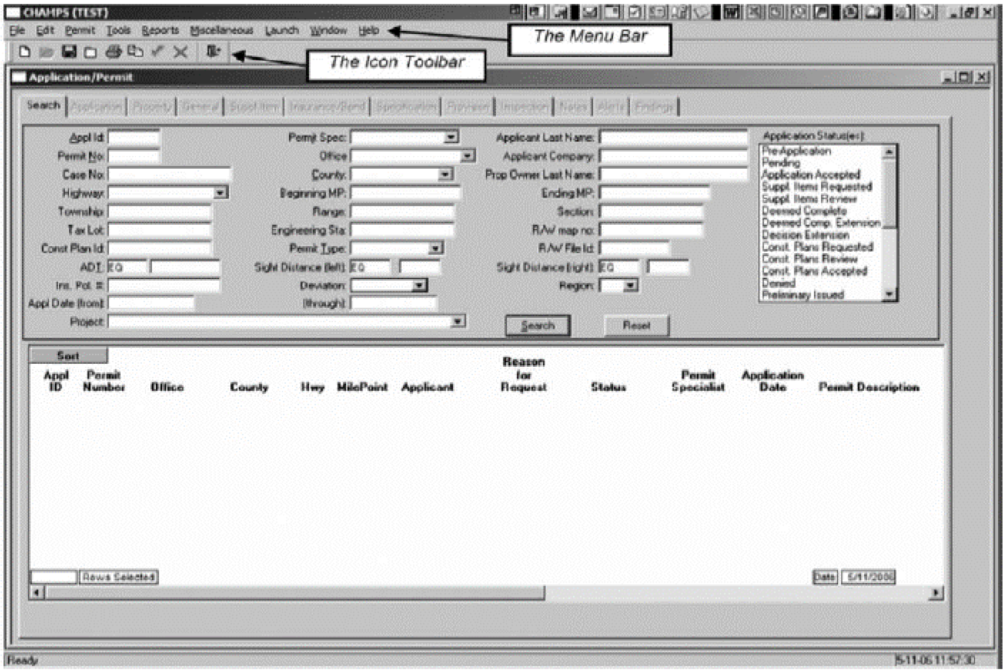

Figure 2.3 Main CHAMPS window

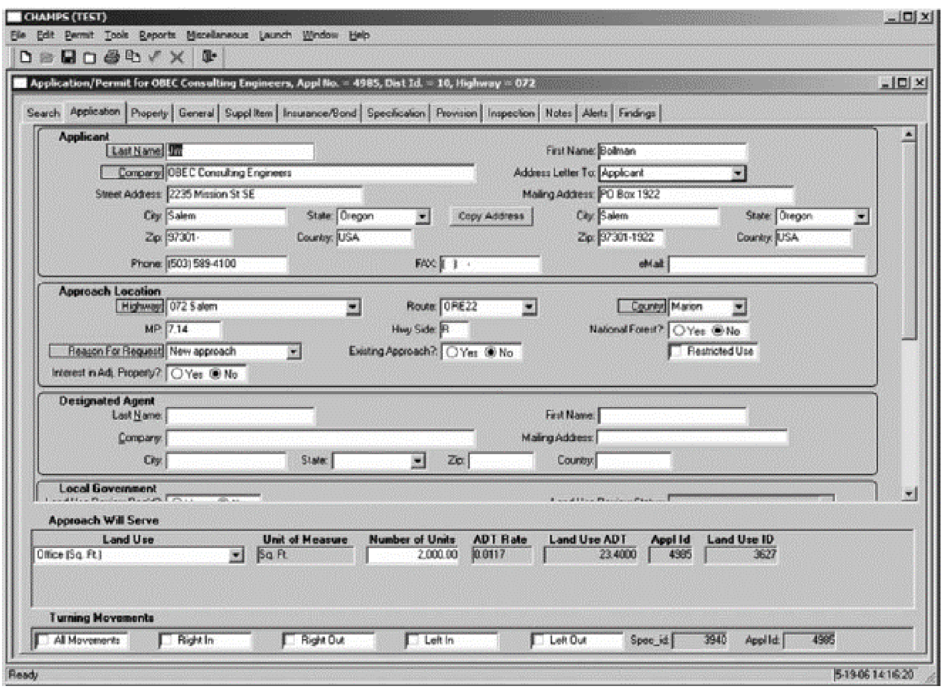

Figure 2.4 CHAMPS Application/Permit Window

CHAMPS also makes it easy to search for individual access permits and group permits by the user simply identifying either the highway number, applicant name, or permit specialist name.

2.5.1.14 ***Utah***

UDOT characterizes access management into three different types being No Access (NA), Limited Access (LA), and Managed Access. No Access only allows access at the interchanges and prohibiting access to the through-traffic lanes controlled by fencing. No Access also prohibits direct driveway connections. Limited Access which is controlled by permit and consist of private driveway connections and access to selected public roads. Managed Access is controlled by permit and follows extensive guidelines. Managed Access consists of conventional highways and establishes access to abutting property.

2.6 Chapter Summary

The literature review has shown that there is a vast amount of information available related to access management strategies and policies that have been implemented around the country and abroad. Many of these strategies have already been implemented in South Carolina and are published in the 2008 ARMS manual. The researchers used the literature review to guide the analysis of crash data presented in Chapter 4. This analysis yields support for which policies, standards, and guidelines that have positive safety impacts as well as those that are recommended to be modified or replaced. Further, the implementation of a context sensitive access management program will help to assure that the most appropriate strategies are used in a particular situation.

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CHAPTER 3: DATA COLLECTION PROCEDURES AND DATA SUMMARY

A great deal of data was necessary for the analyses that are discussed in Chapter 4. These data include crash data, roadway characteristics, and driveway characteristics. This chapter describes the data collection procedures, corridor selection, the GIS database design, and introduces methodologies that are used in the analyses.

3.1 Project Commencement

The Clemson research team participated in several introductory strategy sessions with SCDOT early in the project to discuss necessary tasks to be undertaken and important data to be provided by SCDOT at the onset of the project. The project team developed a framework for obtaining crash databases from 2010 to 2012 from SCDOT. In addition, the South Carolina Access and Roadside Management Standards Manual (ARMS) provides standards and guidelines needed for access encroachments onto SCDOT right-of-way. There are several characteristics of driveways identified in ARMS and many of these characteristics are items that were collected as part of the driveway database discussed in section 3.4. Roadway segment digital shapefiles for South Carolina were already provided to Clemson prior to the initial strategy session. Other data items that would be provided through coordination at the strategy sessions include access waivers and RIMS attributes.

3.2 Initial Crash Geocoding

Three years of crash data were collected and analyzed to identify SC corridors with the highest number of access management related crashes to be included in comparative case studies. Additional years of crash data were also intended to be used for some before and after evaluation of access management implementations however older crash data were known to have spatial limitations from previous research (Sarasua, 2008).

The provided crash data along with associated RIMS attributes were imported into a Geographic Information System. Microsoft Access was the primary platform for working with the crash data while ArcGIS was the platform for geospatial analysis of the crash and roadway data.

The initial geocoding of crash data resulted in a number of systematic errors that were not unexpected because of the research team’s previous work. A process was developed to remove the systematic errors in an effort to maximize the number of crashes that could be geocoded.

It was evident from the initial crash geocoding that the new crash reporting system being used by the South Carolina Highway Patrol has resulted in a vast improvement in locating crashes. The detailed procedures for enhanced geocoding of the crash data as well as an analysis of the improved accuracy of the new system is discussed in detail in Chapter 4.

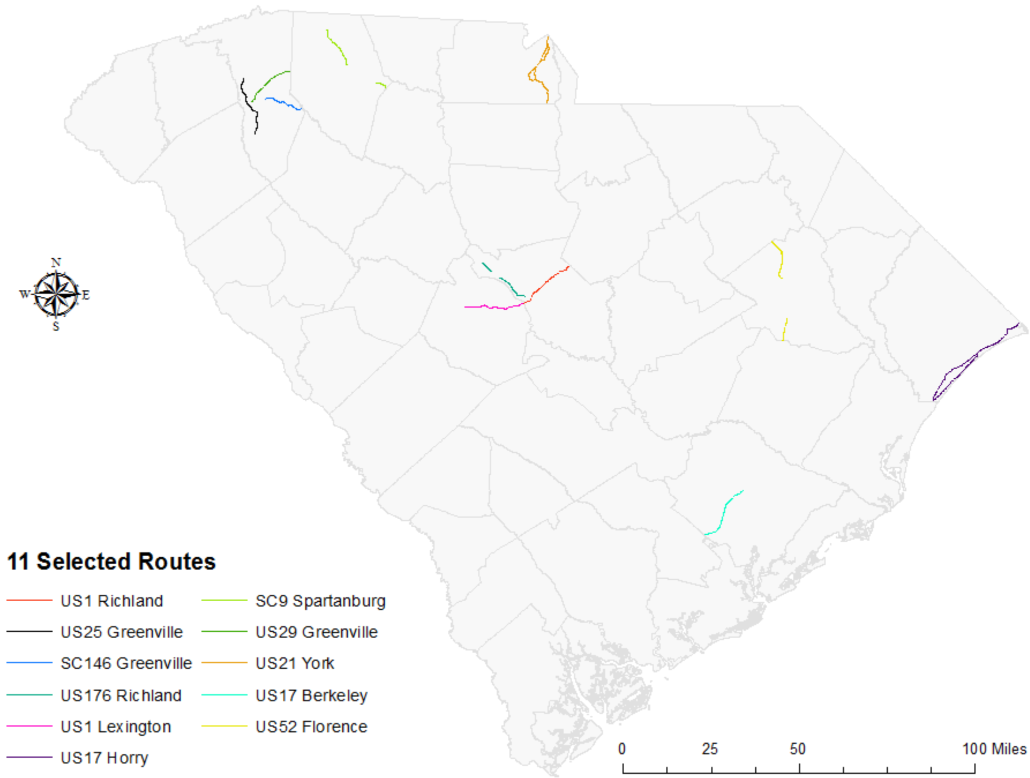
3.3 Corridor Inventory and Selection

A major component of this research was to identity and select corridors within the state with a high incidence of access related crash types for detailed analysis. Microsoft access was used to query the number of driveway related crashes (coded as junction type 02 in the crash database) on a particular US or SC route within a county. These queries were done for three different years; 2010, 2011 and 2012. A ranking of routes based on the frequency of driveway related crashes was created for each year. Ranking decreased with decreasing crash frequency. To reduce the bias towards longer routes created by crash frequency ranking, a combined average rank was created for the three years. This combined average rank was also to account for the fact that crashes are truly random events. The top 30 corridors were identified for potential safety and operational analyses. A final set of 11 corridors (see Table 3.1) was selected from the top 30 based on the combined average rank as well as spatial distribution throughout the state. Figure 3.1 shows the location of the selected corridors.

Table 3.1 Final 11 Corridors

COUNTY	ROUTE TYPE	ROUTE NUMBER	LENGTH (MILES)	3 YEAR DRIVEWAY AVG RANK	DRIVEWAY CRASHES
Richland	US	1	18.5	1	353
Greenville	US	25	18.7	2	309
Greenville	SC	146	13.5	3	294
Richland	US	176	15.8	4	274
Lexington	US	1	17.6	5	214
Horry	US	17	55.4	6	195
Spartanburg	SC	9	15.8	7	173
Greenville	US	29	15.4	8	159
York	US	21	35.6	9	147
Berkeley	US	17	18.8	11	149
Florence	US	52	20.4	12	131

Figure 3.1: Map of 11 Corridors



3.4 GIS Database Design

The next step in the research was to create a driveway database for the 11 selected corridors. A goal of this research is to correlate the attributes of driveways with the incidence of crashes. The South Carolina Access and Roadside Management Standards (ARMS) and the Highway Safety Manual (HSM) were used as guides in the selection of attributes and the data dictionary for the driveway database along with access management related manuals from other states and literature pertaining to road access and roadside encroachment. The driveway attributes and the procedures involved in the attribute data collection are discussed further in the next section.

3.4.1 Description of Driveway Attributes and Identification of Driveways

The initial setup of the routes involved the acquisition of roadway centerline GIS shape files from SCDOT. The urban sections of these shape files were extracted using urban boundary files from the U.S Census Bureau. An empty driveway layer in the form of a point shape file set up with the driveway attribute data column headings was created for each route in ArcGIS. The 11 routes were examined and all driveways were identified using Bing and Google digital aerials and Google street view. When a driveway was identified, it was assigned a point feature. Below is a summary of the driveway attributes collected.

Table 3.2 Driveway Attributes

Attribute	Attribute Code	Inputs	Input Code
Driveway Number	Driveway_N	Number	
Driveway Spacing	D_Spacing	Distance (FT) - Round to nearest foot	
Driveway Turning Radius	D_Radius	Radius (FT) – Estimate	
Driveway Width	D_Width	Width (FT)	
Number of entry lanes	N_Entry_Ln	Number	
Number of exiting Lanes	N_Exit_Ln	Number	
Driveway Angle	D_Angle	Ortho	1
		Skewed	2
Driveway Corner Clearance	D_Corner_C	Distance (FT)	
Driveway Throat Length	D_Throat	Distance (FT)	
Sight Distance	Sight_Dist	Good	1
		Questionable	2
		Bad	3
Driveway Description	D_Type	Right in right out- channalized (painted-obvious geometry or raised)	1
		Right in right out- unchannalized (No left turn sign)	2
		No restriction	3
		Open driveway (too wide)	4
		One-way	5
Auxiliary Lane from road into the driveway	Aux_Lane_R	None	1
		Left	2
		Right	3
		Both	4
Median Type On Roadway	Median_Ty	Single or double solid yellow line/no median/undivided	1
		Raised median (Including aux lane)	2
		Grass Median	3
		Two way left turn lane (TWLTL)	4
		Painted Double Double Yellow Median	5
		Median opening	6
		Aux Left Turn Lane (Bad)	7

Table 3.2 (Continued): Driveway Attributes

Parking Type On Roadway	Parking_Ty	None	1
		Parallel	2
		Angle	3
		Perpendicular	4
Driveway Land Use	D_Use	Commercial	1
		Industrial_Institutional	2
		Residential	3
		Mixed Use	4
		Vacant Developed	5
		Vacant Undeveloped	6
		Other	7
Driveway Class based on volume	D_Class	Low (Single Dwelling Units)	1
		Medium Residential (Sub-Division/Apartments)	2
		Medium (Low turnover small business)	3
		High (fast food, gas station, drivethrough banks…)	4
		Major (Big box)	5
Size of Land Use	D_Use_Size	Low: 0-10 Parking	1
		Medium: 11-50 Parking	2
		Large: >50 Parking	3
		Extra Large: Big box, Mall, High Rise, Parking Block	4
Driveway Use Shared?	Sh_Use	Yes	1
		No	2
Number of Driveways per Use	No_D_Use	One of One	1
		One of Two	2
		One of Many	3
Driveway Hierarchy	D_Hierarch	Primary Drive	1
		Secondary Drive	2
		Not Applicable	3
Contral at Driveway	D_Control	Unsignalized	1
		Signalized	2
Any additional comments	Comments		Text
Data Collector	Researcher	Name of Data Collector	Text

A detailed data dictionary for the database attributes is as follows:

- *Driveway Number*: The driveway number is a number given to each driveway to serve as an identification (ID) field. Driveways were numbered in the direction of data collection along a route (also referred to as the 'working direction' by the team) and not necessarily the driving direction. Directions used were west-to-east or south-to-north.

- *Driveway Spacing*: Spacing between driveways was measured from the furthest point of the current driveway to the closest point of the following driveway in working direction; regardless of the side of the route the driveways were located. The exception to this rule was with sections of routes that had a raised concrete or grass median some other median barrier. The last driveway located before an intersection by default did not have a spacing due to the presence of the intersection. Driveways located directly opposite each other or separated by less than 12 feet had spacing for both driveways measured to the next viable driveway along the working direction.

- *Driveway Turning Radius*: The driveway turning radius was measured linearly from the start of the driveway radius to the perpendicular (extended) line of the driveway throat.

- *Driveway Width*: The driveway width was measured across the consistent throat section of the driveway for driveways that had a throat. Driveway openings from curb-cuts without a clearly noticeable throat were measured from one side of the opening to the other.

- *Number of entry lanes*: This shows the number of clear, marked out lanes entering the driveway.

- *Number of exit lanes:* This shows the number of clear, marked out lanes exiting the driveway.

- *Driveway Angle*: The driveway angle is the angle at which the driveway is connected to the corridor. The driveway angle was categorized as follows – Ortho: for driveways at an angle between 70 and 110 and; Skewed: for driveways at an angle smaller than 70 or greater than 110.

- *Driveway Corner Clearance*: The driveway corner clearance is the distance from a driveway to the closest intersection leg on the same side the driveway is located. The working direction did not apply in this case, therefore the corner clearance for the first driveway after an intersection was measured back to the intersection.

- *Driveway Throat Length*: The throat length of the driveway was measured from the beginning of the driveway to the first possible vehicle conflict point along the throat.

- *Sight Distance*: The sight distance attribute was a qualitative measure that sought to identify if there could be a possible sight distance issue at the driveway. Sight distance was categorized into three categories: good, questionable and bad.

- *Driveway Description*: The driveway description characterizes the driveway into different types. The different types of driveways used were: right-in/right-out (channelized), right-in/right-out (unchannelized), no restriction, open (too wide) and oneway.

- *Auxiliary Lane from road into driveway*: The auxiliary lane attribute represents if there is a designated lane for vehicles turning off the road into the driveway. The driveway could have one of the following four options: none, left, right or both (left turing lane and a right turning lane into the driveway).

- *Median Type on Roadway*: The median on the roadway separates the travel lanes. The median type attribute recorded the type of median along the roadway at the driveway location. Seven median types were considered: single or double solid yellow line/no median/undivided, raised median (including aux lane), grass median, two way left turn lane, painted double yellow median, median opening and aux left turn lane.

- *Parking Type on Roadway*: The parking type attribute shows what kind, if any, of parking is along the roadway at the driveway location. The different types of parking that a driveway could have are: none, parallel, angle or perpendicular.

- *Driveway Land Use*: A driveway is a private road giving access from a public way to a building on abutting grounds. The driveway land use describes what kind of land the driveway leads to. There are a quite a bit of different land uses that a driveway could lead to. These are commercial, industrial/institutional, residential, mixed use, vacant (developed), vacant (undeveloped) and other. The commercial land use type consists of retail stores, fast food, grocery stores, pharmacies, small banks, repair shops, car dealerships/rentals, parking lots/garages, etc. The industrial/institutional type consists of schools, large banks (corporate offices), office buildings, hospitals, dentists, police department, library, etc. Residential types are single family homes, apartment complexes and neighborhoods. Mixed use is used if multiple types of land use are present. The vacant development type is used for lands that have a building/structure but looks abandoned or not in use. The vacant undeveloped is used when there is a driveway that leads to an open lot. The other type is used for unclear or very unique circumstances. Note: the land use types are based on the reviewers own judgment using the available tools.

- *Driveway Class based on Volume*: The class based on volumes attribute is used in order to accurately predict the turnover rate for each driveway/parking lot. These are classified by: low (single dwelling units), medium residential (sub-divion/apartments), medium (low turnover small businesses), high (fast food, gas station, drivethrough banks, etc.) and major (large malls).

- *Size of Land Use*: The size of the land use attribute details the amount of parking for the building the driveway provides access to. It is broken down into four categories: small (0-10 spaces), medium (11-50 spaces), large (>50 spaces) and extra-large (for large malls, high rise apartments, parking garages)

- *Driveway Use Shared*: This attribute shows driveway is shared by more than one establishment (Yes or no).

- *Number of Driveways per Use*: The number of driveways per use represents whether the driveway is: one of one (the only driveway to the land use), one of two or one of many.

- *Driveway Hierarchy*: If the establishment has more than driveway, the driveway hierarchy indicates if the driveway is the primary drive, a secondary drive or not applicable/not clear.

- *Control at Driveway*: The control at driveway shows whether the driveway is signalized or unsignalized

- *Any Additional Comments*: This is a comments field where researchers could tag certain peculiar or questionable driveways or driveways they had questions or issues with collecting data for.

- *Data Collector*: This field was use to record the researcher that did the data collection. Since multiple researchers worked on a few corridors it was helpful to know who collected the data for each driveway in order to do quality control.

3.4.2 Populating the Driveway Database

The platforms used for the driveway attribute data collection were SCDOT RIMS, ArcGIS equipped with a Bing aerial base map, Google Earth, Google Maps, and Google Street view. Depending on the attribute being collected, any one or a combination of these tools were used. The researchers populated the driveway database by analyzing the digital maps. Measurements were taken and compared using different imagery to insure accuracy. Google GIS attributes provided land use information in many instances and Google street view was used to verify land use and driveway geometry. Table 13 summarizes the driveways and intersections along the case study corridors. Table 3.3 is a sample of a driveway the driveway attributes for the driveway selected in Figure 3.2.

Table 3.3 Corridor Information

COUNTY	ROUTE TYPE	ROUTE NUMBER	LENGTH (MILES)	NUMBER OF DRIVEWAYS	NUMBER OF INTERSECTIONS
Richland	US	1	18.5	760	101
Greenville	US	25	18.7	748	78
Greenville	SC	146	13.5	318	27
Richland	US	176	15.8	533	37
Lexington	US	1	17.6	888	67
Horry	US	17	35.2	1366	197
Spartanburg	SC	9	15.8	623	39
Greenville	US	29	15.4	693	75
York	US	21	35.6	1042	85
Berkeley	US	17	18.8	792	46
Florence	US	52	20.4	677	50

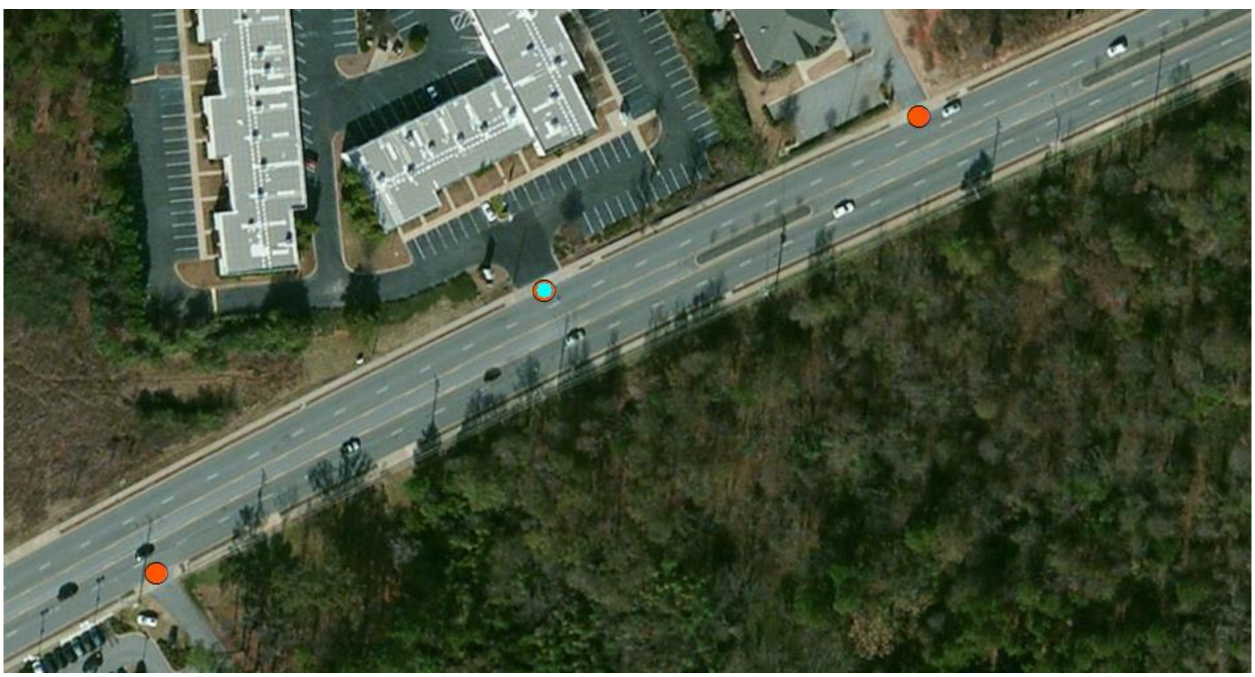


Figure 3.2 Sample Driveway in ARCGIS

Table 3.4 Sample Driveway Attributes

FID	3484	**D_Type**	3
FID_1	3484	**Aux_Lane_R**	1
Join_Count	1	**Med_Type**	4
TARGET_FID	7	**Parking_Ty**	1
POINT_X	0	**D_Use**	2
POINT_Y	0	**D_Class**	4
NEAR_X	0	**D_Use_Size**	4
NEAR_Y	0	**Sh_Use**	2
Id	0	**No_D_Use**	1
Segment_No	0	**D_Hierarch**	3
Driveway_N	13	**D_Control**	1
Seg_Dr_No	0	**D_Control_Binary**	0
D_Spacing	542	**DWidth_P15**	34
D_Radius	20	**Shape_Leng**	63.12232808
D_Width	39	**BUFF_DIST**	34
N_Entry_Ln	1	**Corridor**	SC146Greenville
N_Exit_Ln	1	**Student**	Xi
D_Angle	1	**Check**	0
D_Corner_C	0	**AADT**	12100
D_Throat	45	**SpeedLimit**	45
Sight_Dist	1	**FAorRIRO**	FullAccess

3.4.3 Quality Control

Many of the attributes collected are subjective. Rules were established including examples to help minimize differences among the many researchers involved with entering the driveway data. To further ensure quality control a separate student sampled every 20th driveway to verify the accuracy of the data collection. If systematic differences were found along a particular segment then the entire segment and in some cases selected attributes for an entire corridor were verified.

3.5 Chapter Conclusion

The GIS databases created as part of the research provide the foundation for the analyses in Chapter 4. While managing crashes in a GIS is very common, the literature review showed that the driveway database designed for this research is very unique. In fact, the researchers were unable to identify previous research that used a driveway database (GIS or otherwise) for any reason except to maintain access management waivers (Hearne, 2003; Khan 2007).

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3. Sarasua, W., J. Ogle, and K. Geoghegan. “Use of Global Positioning System to Identify Crash Locations in South Carolina.” Transportation Research Record: Journal of the Transportation Research Board, Vol. 2064, No. 1, 2008, pp. 43-50.

CHAPTER 4: SAFETY ANALYSIS

This chapter presents the different safety analyses that were conducted as part of the research. As the research team progressed through the work plan, several modifications were necessitated due to small sample sizes, missing or incomplete data, and other data coding issues. These issues will be discussed in the relevant sections. The following sections include analysis related to:

1) Access Management Waivers,
2) Crash Geocoding and Spatial Analysis,
3) Crash Rates,
4) Crashes Associated with Driveways,
5) Crashes Associated with Intersection Corner Clearance, and
6) Crashes Associated with Medians and Right-In Right-Out Driveways,

4.1 Access Management Waivers

Of particular interest to the SCDOT are access waivers which are granted in cases of undue hardship caused by strict adherence to the ARMS (Chapter 1, Section 1E) (SCDOT, 2008). Specifically, SCDOT would like to ensure that potential safety and operational consequences are understood so that an informed decision can be made when granting or denying a waiver. To address this concern, the project team first analyzed waiver applications and identified the types of access requests. A summary of the waivers by category (for Richland County) are provided in Table 4.1. In total, there were 58 waivers, granted between 2007 and 2012. Most involved variances on multiple ARMS parameters. Of the reasons cited in the waivers, driveway spacing was the most cited with 35 waivers, and corner clearance was cited in 21 waivers.

To analyze the waivers' safety and operational implications, the project team sought to identify the locations where access management waivers have been approved. The purpose for compiling this data was twofold. The first purpose was to conduct a before-and-after safety analysis of locations that were granted access waivers, and the second purpose was to identify corridors with multiple access management waivers and those corridors with no waivers and a high standard of access management. Having these two types of contrasting corridors would allow for an interesting cross sectional study, assuming that they both have similar parameters (e.g. traffic volume, corridor speed, driveway density). Figure 4.1 shows the spatial distribution of the waivers in Richland County.

Table 4.1 Summary of waivers by category (or combination of categories) for Richland County (2007-2012)

Category	Number of Waivers
Driveway Spacing	18
Sight Distance	8
Driveway Spacing Corner Clearance	8
Corner Clearance	4
Driveway Spacing Driveway Throat Length	4
Corner Clearance Driveway Throat Length	3
Driveway Throat Length	2
Driveway Width/Radius Driveway Throat Length	1
Corner Clearance Driveway Width/Radius	1
Driveway Spacing Corner Clearance Driveway Location	2*
Sight Distance Driveway Spacing Corner Clearance	1
Driveway Spacing Driveway Width/Radius Driveway Throat Length	1
Sight Distance Corner Clearance Driveway Location	1
Driveway Spacing Corner Clearance Driveway Throat Length	1
Other**	2
N/A***	1

* One waiver consisting of two locations (counted as two waivers)
** Reason for waiver listed under “Other”
*** Reason for waiver not listed

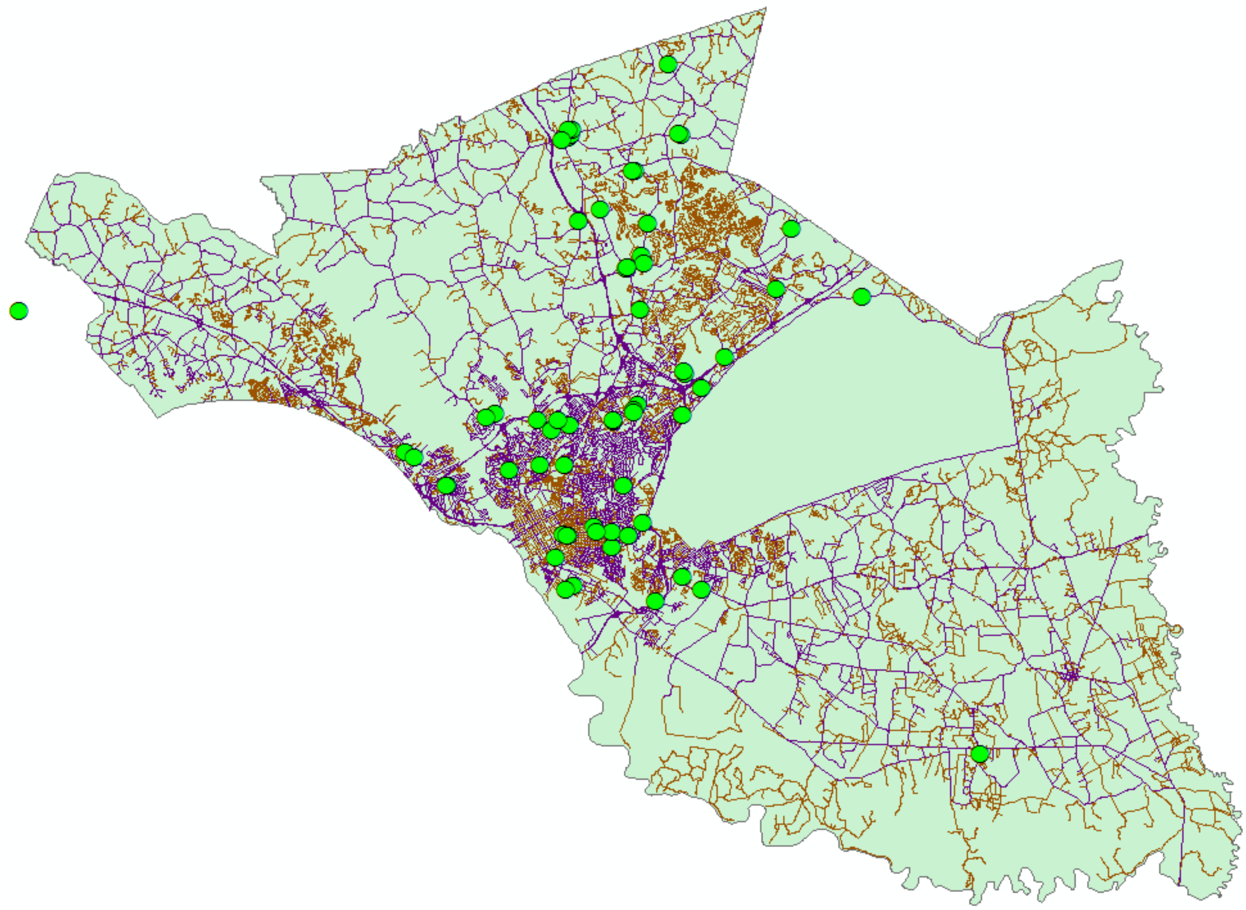


Figure 4.1 Location of waivers in Richland County

To perform the before-and-after study, each waiver location was analyzed using its before-construction and after-construction images, as illustrated in Figure 4.2 for waiver number 11-98777. Then, crash data were retrieved for each of these locations. Ideally, the research team would have two to three years-worth of crash data before the construction of the driveway and after the construction of the driveway. Unfortunately, for all of the waiver locations, there is an insufficient crash history available to allow for statistical analysis of whether those newly constructed driveways contributed to driveway-related crashes. The most prominent issue with the before-and-after study is the inaccuracy of the locations recorded in 2010 crashes and prior. Similarly, the cross-sectional study was not possible because there were not enough waivers concentrated in a short segment along a corridor.

The analysis of waivers did help the research team focus on several common issues related to driveways with potential safety and operational factors. While crash data was not prolific for any one driveway waiver, the number of driveways with ARMS violations are numerous. Therefore, researchers sought to conduct alternative safety analyses related to driveway spacing, corner clearance, and driveway type.

Figure 4.2 Example of before and after-construction of driveway

4.2 Crash Geocoding

The first step required for analysis of crashes associated with driveways was to geocode crashes and determine the proximity to driveways. A secondary step involved coding driveway and corridor characteristics as identified in Chapter 3.

4.2.1 SCDOT Crash Location Reporting

Accurate crash reporting helps to improve the reliability of processes such as crash location identification and evaluation of countermeasure effectiveness. In 2004, SCDOT made an improvement in reporting crash locations by transitioning to the use of GPS technology by law enforcement officers. The use of GPS was not automated. An officer would read the coordinates displayed by the GPS and then write them on the paper crash report. Information from the paper report would later be keyed into a digital database. Although use of GPS units was advantageous over traditional location referencing methods used previously (e.g. distance from intersection, milepoint, etc.), there were a number of issues associated with operation of the units and the recording of location data on paper crash reports (Sarasua et al., 2008).

In 2008, an initiative was undertaken to further improve crash data collection, reporting and processing. The initiative was a coordinated multi-agency effort led by the Traffic Records Coordinating Committee (TRCC). Agencies involved in the TRCC are South Carolina Department of Public Safety (SCDPS), South Carolina Department of Transportation (SCDOT), South Carolina Department of Motor Vehicles (SCDMV), South Carolina Judicial Department (SCJD) and South Carolina Department of Health and Environmental Control (SCDHEC) (Stantec, 2013). The effort by the TRCC resulted in the implementation of an automated crash data collection system called the South Carolina Collision and Ticket Tracking System (SCCATTS) to be used by law enforcement (Stantec, 2013). This system enables officers to spatially see and locate crashes via a GIS-based GPS enabled mapping platform in police vehicles. The GPS would display the vehicle's location on the GIS map display and then the officer has the ability to pinpoint the actual location of the crash. This is important, because an in-vehicle system will report the location of the officer's vehicle (e.g. on the side of the road or in a parking lot) rather than where the crash actually occurred. The officer can input all other information related to the crash, and it can be uploaded immediately or transferred later when the vehicle is in range of wireless network. The deployment of the system began in 2010 and currently all highway patrol vehicles and 60 of over 200 local law enforcement agencies have been equipped with SCCATTS. An additional 20 agencies have completed the training to begin reporting.

4.2.2 South Carolina Crash Data Evaluation and Geocoding

Over the past decade, the aforementioned two major initiatives have proven to be effective in improving crash data. This conclusion was based on a comparison of 9 years (2004 – 2012) of South Carolina crash data. A review of the data for all 9 years resulted in the identification of several systematic errors and erroneous inputs that were consistent with findings from a previous study by Sarasua et al (2008). The researchers removed systematic errors which resulted in more than 96 percent of 2010 highway patrol crashes geocoded successfully and over 99 percent of 2012 highway patrol crashes.

Additional spatial analysis that focused on the accuracy of geocoded crash data was conducted to to determine the suitability of the crash data for analyzing the driveway safety. Three years (2010-2012) of crash data, with systematic and random errors removed, was geocoded. The highest ranking corridors from a driveway crash standpoint were the focus of this study. The majority of 2010 crash data was collected by officers using a hand-held GPS unit while 2011 and 2012 data were collected using GIS-based map equipped with GPS (SCCATTS). An indication of the difference in precision of the two methods can be seen in Figure 4.3. The US-25 corridor example in Figure 4.3 shows that while 2010 crashes are mostly located on the sides of the roadway, or in parking lots, most of the 2011 crashes are shown on the roadway and in the location most likely to be where the crash actually occurred. A probable explanation for why 2010 data were mostly off the roadway is that most police officers would park their vehicles on the side of the roadway, or in parking lots, when filling out parts of the crash report and would read and record GPS coordinates on the GPS unit wherever they were parked. The 2011 and 2012 data collection using the GPS enabled GIS-based map provided the police officers the tools to identify approximate crash location using GPS, and then accurately locate (or pin) the crash at the precise location it occurred on the map, even when parked on the side of the road, or in a parking lot.

A proximity analysis was conducted to determine if there was a change in crash location relative to a roadway's centerline before and after the implementation of the SCCATTS. The distance of each crash from its reported corridor was calculated and averaged by corridor using spatial analysis tools in ArcGIS for the 3 years. Table 4.2 shows the results of the proximity analysis for the top 5 selected corridors based on average driveway crash rank. As expected, Table 4.2 shows that 2010 crashes were further away from their reported route centerline than the 2011 and 2012 crashes. These results clearly show considerable change in the precise location of crashes from 2010 (predominantly recorded with a hand-held GPS unit) to 2011 (predominantly SCCATTS).

Figure 4.3: Rear-end and angle crashes on US 25 in Greenville, SC for 2010 (left) and 2012 (right) (images from Bing Maps)

Table 4.2 Average Distance from Reported Route by Year

Route	Average Distance (FT)		
	2010	2011	2012
US 1, Richland	14.6	3.7	3.2
US 25, Greenville	17.8	2.4	1.3
SC 146, Greenville	18.6	1.8	1.0
US 176, Richland	15.3	1.7	1.1
US 1, Lexington	14.7	4.4	4.7

4.2.3 GIS Travelway Buffer Creation

SCDOT maintains a GIS layer of roadway centerlines for all roads on the South Carolina state route system. Attribute data is either associated with an entire centerline segment or linear referenced by mile point using dynamic segmentation. Offset lines such as lane lines, edge of pavement, and travelway limits are not included as GIS data layers. Travelway polygons were determined to be vital for analyzing driveway safety and thus needed to be created prior to the analysis. The buffer by attribute capability was used in ArcGIS to synthetically generate edge of travelway polygons for all five analysis corridors. Buffering using buffer by attribute creates a polygon based on an attribute of individual segments, which in this application, buffered the roadway centerline segments using the buffer distance as half of the travelway width attribute value, as identified in the South Carolina Roadway Inventory Management System (RIMS) database. For the most part, the resulting travelway buffer followed the underlying aerial imagery very well however, there were some problems. In some cases, the GIS roadway centerline did not follow the actual centerline causing the buffer to be offset in places. Another problem identified the RIMS travelway width attribute for some segments is coded incorrectly. Figure 4.4 provides examples of buffered travelway that included errors (left) along with corrections (right).

While the proximity analysis indicates a distinct change in the average distance from centerline for crash data collected after 2010, an additional evaluation was conducted to identify the proportion of crashes that fell within the roadway corridor's travelway, before and after implementation of SCCATTS. Using a GIS point-on-polygon spatial aggregation, the crash data is overlaid with the travelway buffer polygons to identify crashes that are geocoded within the travelway corridors. Table 4.3 shows the results of this analysis. It shows that only 27 to 48 percent of the 2010 crashes fall within the travelway even though it is likely that nearly all of the types of crashes used in this analysis occurred in the travelway. It should be noted that fixed object and run-off-the-road crashes were omitted from the analysis because these crashes are typically not driveway related. Further analysis of the sections of the routes listed in Table 4.3 reveals that 2010 crash percentages do not represent the potential conflict points, which should all be on the travelway. However, 2011 and 2012 crash data realistically represent potential conflicts on the travelway. In 2012, over 95% of the crashes occur within the travelway buffer where actual conflict points exist.

TABLE 4.3 Percent of Highway Patrol Crash Data Identified by Corridor by Year

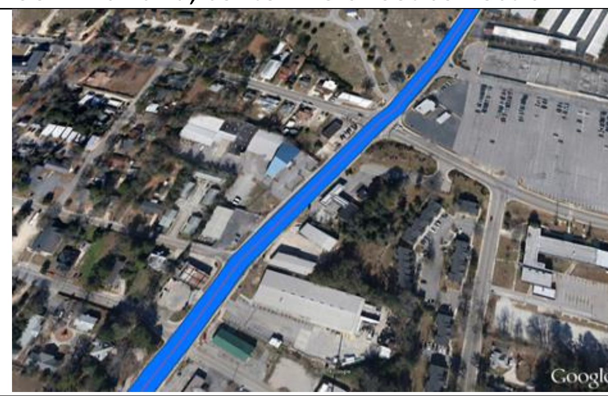
		2010 Crashes			2011 Crashes			2012 Crashes		
Route	Miles	HP	In TW	In TW%	HP	In TW	In TW%	HP	In TW	In TW%
US1 Richland	18.3	620	411	66.3	726	712	98.1	681	679	99.8
US25 Greenville	18.7	755	404	53.5	833	649	80.1	836	692	82.8
SC146 Greenville	11.7	372	201	54.0	506	489	96.6	550	545	98.9
US176 Richland	14.1	413	258	62.5	445	420	94.4	533	513	96.2
US1 Lexington	17.7	384	233	60.7	419	381	94.2	436	388	89.1
SC9 Spartanburg	15.6	300	167	55.7	344	325	94.5	363	345	95.0
US 17 Berkeley	18.7	335	147	43.9	337	267	79.2	370	325	87.8
US21 York	35.6	151	115	76.2	201	191	95.0	195	185	94.9
US52 Florence	20.3	192	118	61.5	250	212	84.8	123	88	71.5
US17 Horry	55.4	737	455	61.8	815	724	88.8	784	706	90.1
US29 Greenville	15.4	282	202	71.6	308	297	96.4	349	349	100

Notes:
1.) HP – SC Highway Patrol
2.) In TW – Number of crashes located by GPS within defined corridor travelway
3.) In TW% – Number of crashes located by GPS within defined corridor travelway as percentage of total known corridor crashes, based on SC HP crash records

US 1 Richland, centerline offset problem

US 1 Richland, centerline offset correction

US 1 Richland, travelway width problem



US 1 Richland, travelway buffer correction

FIGURE 4.4 Results of the GIS travelway buffer operation including corrections.

4.2.4 Using Accurate Crash Locations to Facilitate Safety Analysis of Access Management Practices.

Reliable crash data that provide accurate crash locations is essential for safe access management practices *(Chowdhury, 2005)*. The improved spatial accuracy of crashes makes it possible to pinpoint the locations where clusters of crashes occur in relation to a driveway. This is evident at the location shown in Figure 4.5 on US 1 in Columbia, South Carolina. The image shows a number of driveway related crashes (shown with stars) occurring when vehicles attempt to enter or exit from adjacent fast-food restaurants across a left-turn bay. The accuracy of crash data prior to 2010 would not produce evidence of these clusters, making it difficult to identify where crashes occur relative to driveways unless the sketches made by officers on the original crash reports are analyzed individually. In the next several sections, we will discuss several safety analyses using the most accurate 2012 crash data.

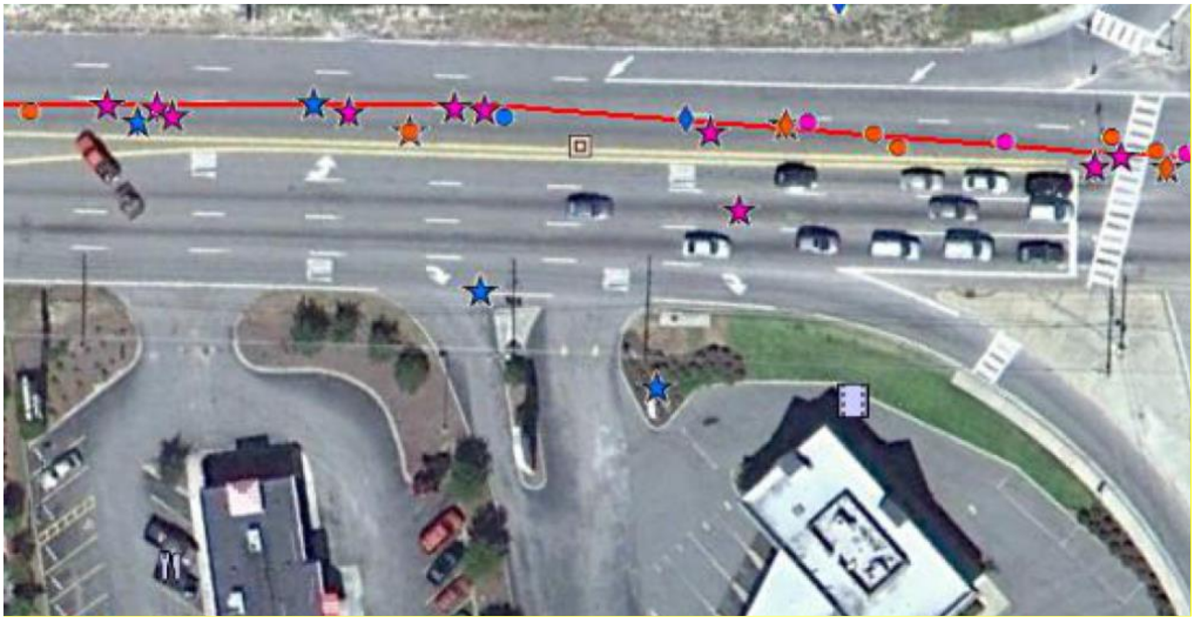


FIGURE 4.5 Driveway related crashes over a three year period on a section of US Highway 1 in Richland County, South Carolina.
* Note the proximity of the crashes relative to the left-turn bay

4.3 Development of Driveway Crash Rates

To determine the effects of the characteristics of driveways on crash incidence, it is necessary to associate driveway crashes with driveways. This presents two very difficult problems that must be overcome. First, it is necessary to distinguish driveway crashes from other crashes; and second is to develop a one to one association of a driveway crash to a particular driveway. Only then is it possible to determine driveway crash rates.

4.3.1 Issues With Junction Type

For the first problem, it would be ideal to just use "junction type=driveway" as indicated in crash reports. However, an analysis of the crash data indicates that many obvious driveway related crashes would be omitted. Many crashes occur within close proximity to driveways or in the two way left turn lane (TWLTL) that, in most cases, are likely driveway related. A study of midblock crashes along selected corridors that occur in TWLTLs not near intersections showed that less than 25% were coded as "junction type=driveway". Figure 4.6 demonstrates several crashes (indicated by X's) that were coded as "junction type=no junction" It is apparent from this analysis that only using crashes coded as driveway crashes will underestimate the crash incidence related to access management policies. Thus, the researchers only eliminated crash types that were unlikely to be driveway related such as fixed object and run-off-road crashes.

FIGURE 4.6 Driveway related crashes coded as "no junction".

Table 4.4 shows that roughly 25% of highway patrol crashes that fell within driveway buffers along our sample of corridors are actually coded driveway crashes in the crash report. Another 25% of those crashes falling within driveway buffers are considered occurring at some sort of intersection (4-way intersection, T-intersection, Y-intersection, etc.). Note that only segment crashes were used in this analysis – all crashes in the intersection influence areas were removed. Finally, the majority of the crashes falling within the driveway buffers were considered 'no junction' by the highway patrol.

Table 4.4 Junction Type Coding for Crashes within Driveway Buffers

Junction Type Codes	Frequency	Percent
0 - Blank	53	3.1%
1 -Crossover	10	0.6%
2- Driveway	435	25.8%
4 - 4way Intersection	164	9.7%
5 - Railway Grade Crossing	3	0.2%
8 - T Intersection	268	15.9%
12 - Y Intersection	5	0.3%
13 - No Junction	749	44.4%
99 - Unknown	1	0.1%
	1688	

4.3.2 Driveway Buffer Creation

After querying possible crash types that could be associated with driveways and ignoring others, the analysis assumption is that any crash in an influence area of a driveway is a driveway related crash of that driveway. It is crucial that the driveway influence areas are as precise as possible in order to evaluate the driveways effectively. One approach is to use ArcGIS buffer techniques to buffer an area on the travelway adjacent to each driveway to delineate the influence area. Once these buffers are created, they can be overlaid with underlying crashes to do the association. One problem with this approach is that the resulting driveway buffers would be circles around the point that represents the location of the driveway. This would bias crashes that occur closer to the side of the road. Ideally, rectangular buffers would give a better indicator of a driveway's influence area. Thus, the researchers created a model that could make rectangular buffers that stretched across the roadway. Two models were created depending on driveway type—one model for right-in-right-out (RIRO) driveways and one model for full access driveways.

The first model designed was created in order to project the RIRO driveways. Since these driveways do not accommodate left turns the buffer stretches from the edge of pavement, where the driveway starts, to the centerline of the roadway. Before this model could be run, all of the RIRO driveways were selected and exported into a new ArcGIS shape file. The model takes three inputs, the RIRO driveway points, driveway width data, and the roadway centerline segments. The model creates a new table and then adds the x and y coordinates of a RIRO driveway and then it creates a perpendicular line from the driveway point to the closest point on the roadway segment. Next, the driveway width attribute is associated with the line and is used to create the finished driveway buffer. The driveway buffer width is the driveway width plus thirty feet to accommodate about a car length on each side of the driveway (Figure 4.7). The 30 foot value was identified in a separate analysis using different values starting at 0 (thus the driveway influence area would only be equal to the actual driveway width) to 60' in 6 foot increments. The number of crashes that fell within each buffer was determined and graphed. An inflection (abrupt change in slope) occurred for 30 feet.

Figure 4.7 Right-In-Right-Out Driveway Buffers

The full access driveway buffer model is a bit more complicated. A few extra steps had to be done before this model could be run. Similar to the RIRO driveways, all full access driveways were selected and exported to a new shape file. The variable road segment buffer described in section 4.2.3.2 that represented the travelway width was also necessary for this model. Next, two new point shapefiles were created: Top and Start/End. The Start/End points were place on each end of the travelway buffer and the Top point was placed within thirty feet of the top of the corridor buffer. After all the input files (full access driveways, travelway buffer, Top, and Start/End) were created the model could be run. The model follows a similar process to the RIRO driveways but is more involved and has more steps which are not discussed here. The full access driveway buffer can be seen in Figure 4.8. Both models were used for each corridor individually.

Figure 4.8 Full Access Driveway Buffers

4.3.3 Driveway Summary Statistics

Once the driveway buffers were created, numerous types of analyses could be conducted. To analyze the safety of the driveways, the research team determined how many crashes occur within the driveway buffers. This was done by aggregating the 2012 driveway related crash data into the driveway buffers using a GIS overlay. The resulting crash count in each buffer gives the 2012 crash rate for each driveway. The average crash rate of the 11 corridors represents the total number of crashes that fell within driveway buffers divided by the total number of driveways. The overall driveway crash rate for the 11 corridors is 0.22 crashes per driveway per year. The same process was completed for each corridor individually and the results are shown below in Figure 4.9.

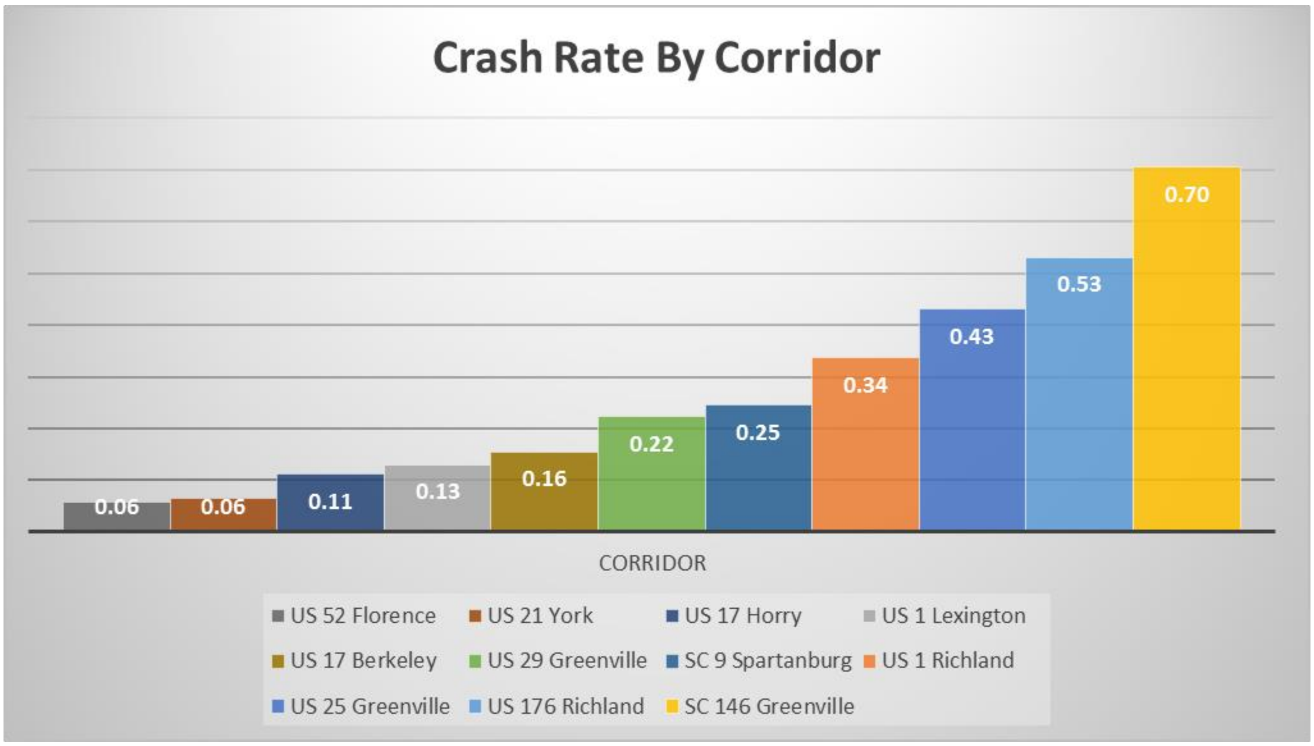


Figure 4.9 Crash Rate by Corridor (Year 2012)

Given the wide variations in crash rates for these 11 corridors, further evaluation was conducted to determine the potential causes of the disparity. As mentioned previously it is very important to accurately geocode the locations of crashes when dealing with spatial data analysis. For some of these corridors the highway patrol only reported a small portion of the total number of crashes along the corridor with the majority of crashes being reported by local authorities not equipped with the new SCCATTS system. Table 4.5 shows a comparison of the crash rate and the proportion of crashes recorded by highway patrol. It is not coincidental that the corridors with the lowest driveway crash rates have the lowest proportion of crashes recorded by highway patrol. To minimize the potential bias associated with corridors with a high proportion of crashes not being recorded with SCCATTS, only those corridors with a highway patrol crash reporting proportion greater than 70% were considered for further analysis. This threshold was chosen to minimize the disparity while still allowing the majority of the selected corridors to be used in the detailed analysis. These corridors include US 1 Richland, US 176 Richland, SC 146 Greenville, US 25 Greenville, SC 9 Spartanburg and US 17 Berkeley. After removing the other 5 corridors the overall driveway crash rate increased to 0.36 crashes per driveway based on 2012 crash data. The next several subsections summarize crash rates for different driveway characteristics.

Table 4.5 Comparison of Crash Rates and the Crash Reporting Agency

Corridor	Crash Rate	SCHP	All	Proportion
US 52 Florence	0.06	138	531	26.0
US 21 York	0.06	211	755	27.9
US 17 Horry	0.11	801	1773	45.2
US 1 Lexington	0.13	458	759	60.3
US 17 Berkeley	0.16	393	543	**72.4**
US 29 Greenville	0.22	404	777	52.0
SC 9 Spartanburg	0.25	397	414	**95.9**
US 1 Richland	0.34	722	987	**73.2**
US 25 Greenville	0.43	927	1042	**89.0**
US 176 Richland	0.53	584	696	**83.9**
SC 146 Greenville	0.70	603	777	**77.6**

4.3.3.1 Crash Rate by Driveway Class

The driveway class was recorded to demonstrate the safety effects of the turnover rate of driveways. A residential driveway with a ‘low’ driveway class designation represents a single family dwelling unit. ‘Medium’ driveway class was used for residential subdivisions with more than a few houses and apartments. Businesses with low turnover such as small offices and small sit-down restaurants were also assigned to the ‘medium’ driveway class. ‘High’ turnover driveways include fast food restaurants, gas stations and drive thru banks. The final driveway class of ‘major’ is for big box commercial developments, local shopping centers, malls, and other significant commercial developments. The crash rates follow the expected trends with the rates increasing as the class goes up. This shows that this driveway ‘class’ is very important when considering the safety aspects of implementing future driveways The classes were manually assigned by the data recorders after extensive training. The results can be seen in Figure 4.10 below. The figure shows that the major driveway class has nearly 10 times the crash rate of a low category driveway. Note that the rates are for driveways that are on State Routes with significant traffic volume. Crash rates on residential streets will undoubtedly be much lower.

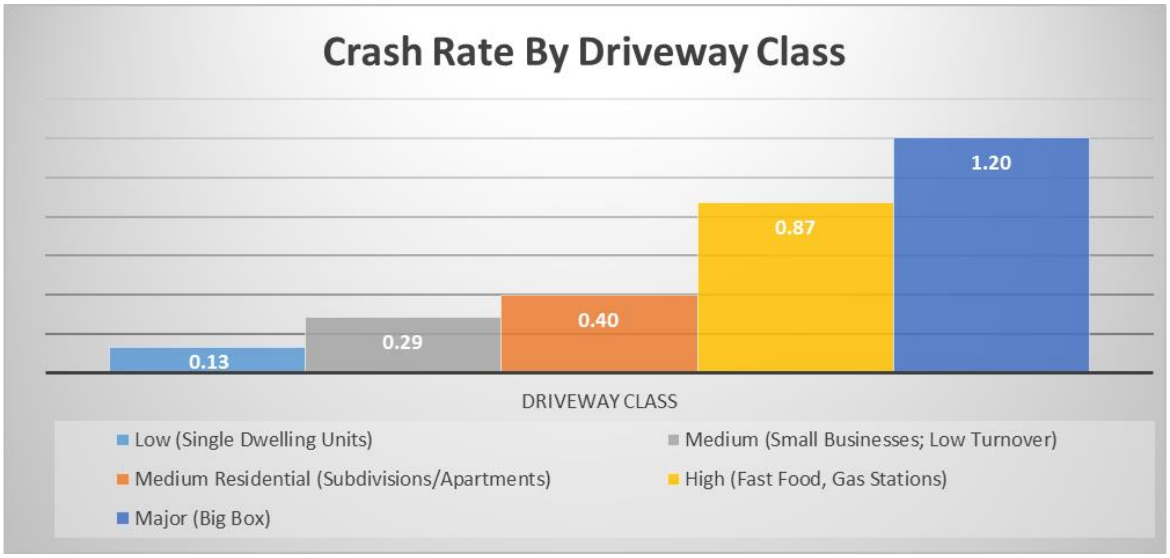


Figure 4.10 Crash Rate by Driveway Class

4.3.3.2 Crash Rate by Driveway Land Use/Parking Size

Similarly to the driveway class, the land use/parking size was another attribute recorded as a way to estimate the volume of vehicles using the access point. This attribute is also easier to record because it is solely based on the parking lot size. The different groups for this attribute are: low, medium, large and extra-large. Low parking is for land uses with 0-10 parking spaces, medium is for driveways that lead to 11-50 parking spaces, and large is for land uses with greater than 50 spaces or high-turnover fast food restaurants with 40 or more spaces. The last category is extra-large which is used for big box commercial, malls, and high rises. The result for this driveway Characteristic is shown in Figure 4.11 below.

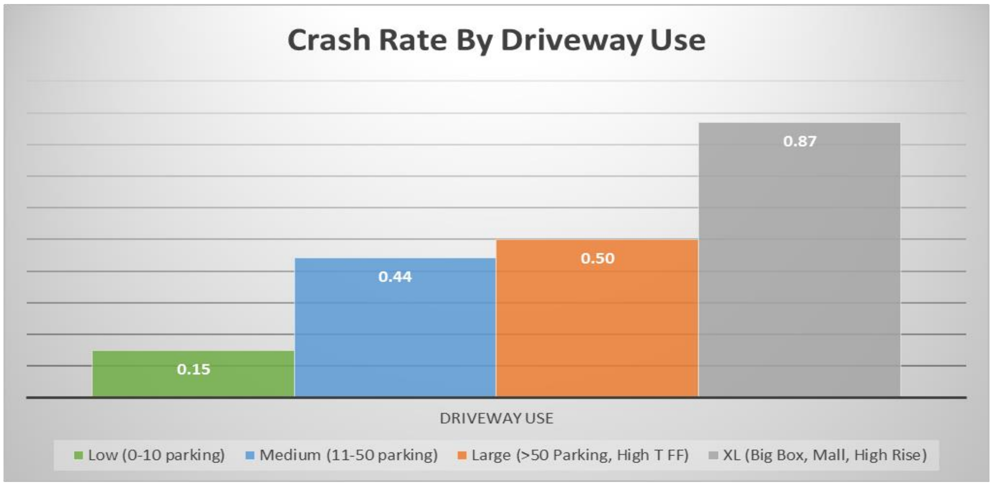


Figure 4.11 Crash Rate by Driveway Land Use/Parking Size

4.3.3.3 Crash Rate by Driveway Type

Driveways can have a variety of different configurations. The driveway type field categorizes the driveway as one of the following: Right-in Right-Out (RIRO)– Channelized, RIRO – Unchannelized, No restriction, Open driveway (continuous), or one way. Channelized RIRO driveways include well marked, obvious geometry, use of islands, or raised medians that force one to make the right turn only. Unchannelized driveways may have painted turn arrows but may experience wrong-way movements. No restriction driveways are full access driveways, and open driveway configurations have continuous driveway openings or mountable curbs where access can occur all along the property. Figure 4.12 shows the crash rates by driveway type. The figure shows that open driveways experience the highest crash rate of 0.76 crashes/driveway. This may be because of the larger conflict area that is typical of this type of driveway. The data indicates that the RIRO driveways have a crash rate that is less than half that of full-access driveways and roughly 20% of open driveways.

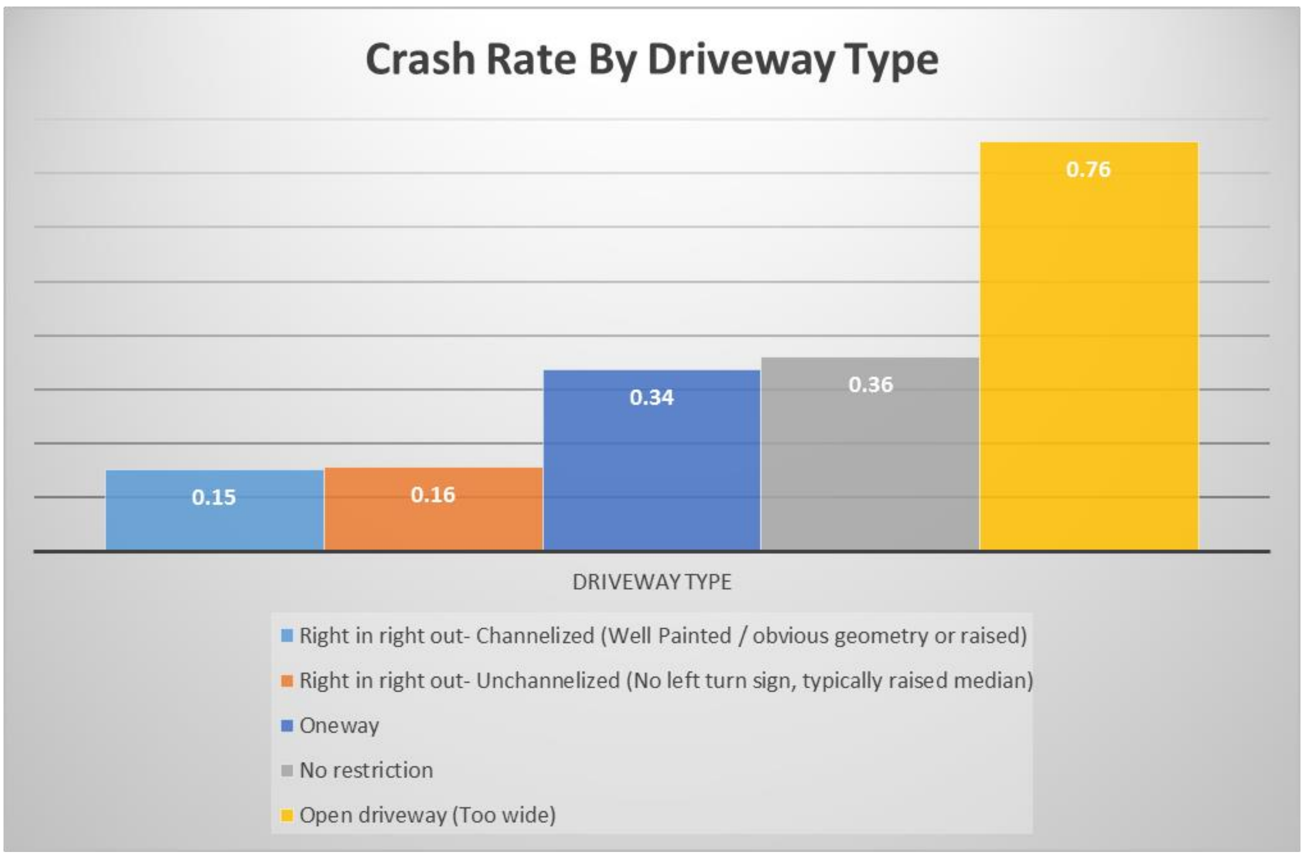


Figure 4.12 Crash Rate by Driveway Type

4.3.3.4 Crash Rate by Median Type

The literature review indicates that median type is a significant contributor to crash incidence related to driveways. Seven different median types were considered in the data collection process. The most common median type in the United States is the single or double solid yellow line undivided. The data indicated that the undivided category had a surprisingly low crash rate relative to other median types. This finding is contrary to existing literature, thus the research team looked further. It was shown that most of these driveways were adjacent to undivided roads with about 9,000 less vehicles per day than the average AADT across all corridors, as well as with much larger driveway spacing than typical for the corridors. Findings introduced later in this report indicate that increased AADT and reduced driveway spacing experience higher driveway crash rates. The next two types of medians that were considered were raised and grass medians. These median types all but guarantee that drivers will not make a left turn or cross the median - which in turn limits the number of conflict points and conflict types (e.g. no crossing conflicts). Both of the crash rates for these were very low, with 0 for grass medians (0 crashes for 12 driveways with grass medians) and 0.14 for a raised median. A painted double-double yellow line legally prohibits crossing maneuvers; however, drivers typically cross these markings if it is more convenient to do so. The higher crash rate of painted double-double yellow lines confirms this. One median type that is prevalent in urban areas with a lot of access points is a two-way left-turn lane (TWLTL). The TWLTL has a fairly high crash rate relative to road configurations with raised medians. Driveways in close proximity to intersections where vehicles typically cross intersection auxiliary lane markings have a crash rate nearly fifty percent higher than the average driveway crash rate. The highest crash rate for the median types is if there is an opening to a continuous median allowing cars to make turns. This crash rate is 0.97 crashes/driveway. The higher rate is likely due to median openings serving multiple driveways. The crash rate is higher for the driveway nearest to the median opening, while all of the nearby driveways will have a much lower crash rate benefiting from the raised median. The driveway crash rates by median type are shown in Figure 4.13.

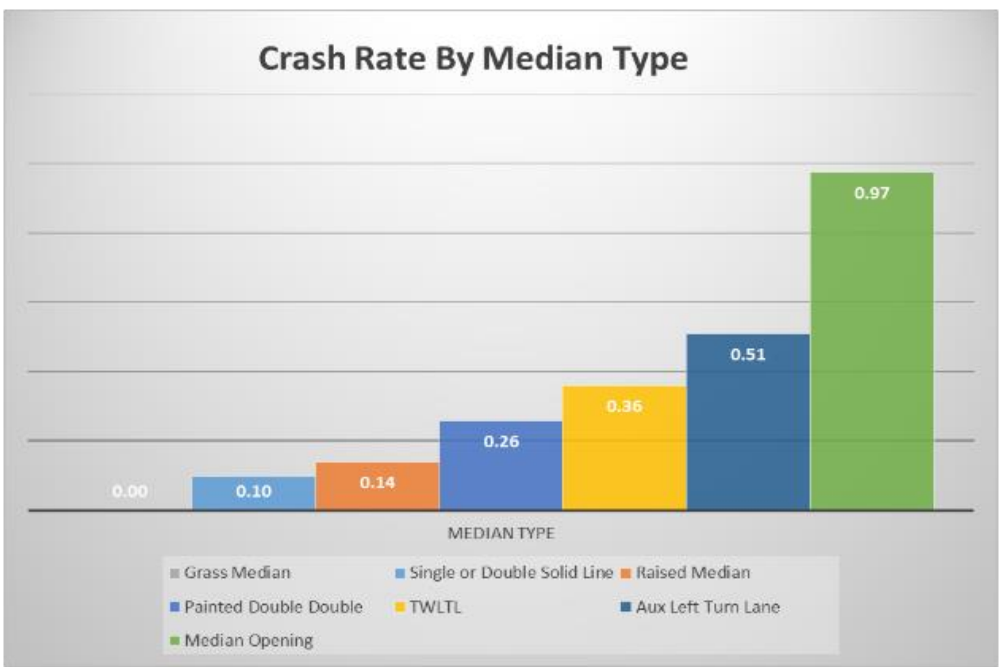


Figure 4.13 Crash Rate by Median Type

4.3.3.5 Additional Crash Rates

Figures 4.14 and 4.15 represent the crash rates for if the driveway is a primary or secondary (if there are multiple driveways for a single land use), and if the driveway is signalized.

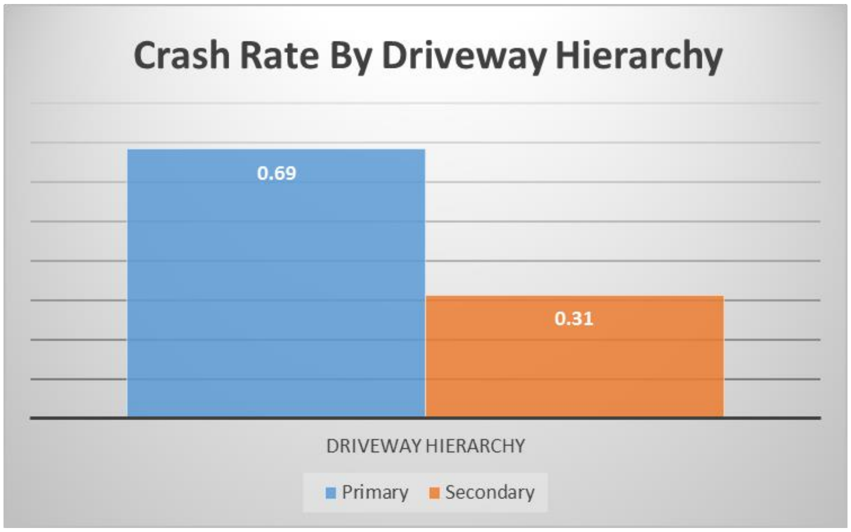


Figure 4.14 Crash Rate by Driveway Hierarchy

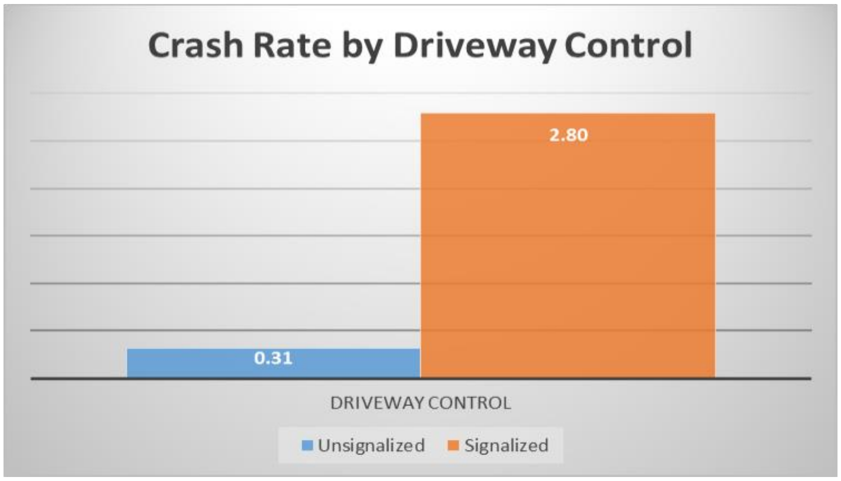


Figure 4.15 Crash Rate by Driveway Control

4.4 Statistical Analysis of Driveway Crash Data

While the driveway crash rate summary statistics provide insight into the crash experience of each driveway, the rates can be deceiving due to the confounding effects of other driveway characteristics and biases toward small denominators. In this section, models are developed to predict the contribution of individual driveway characteristics to crash incidence and determine the statistical significance of this contribution.

4.4.1 Negative Binomial Analysis

Vehicle crashes are random, discrete, and non-negative. As such, commonly used models to study traffic crashes are the Poisson and negative binomial regression models. Another reason for their popularity is their ability to identify effectively model a broad range of risk factors for crashes, and thus, provide valuable information for traffic engineers to select mitigation measures. Between the Poisson and negative binomial models, the Poisson model was deemed not appropriate for this study because the mean and variance of the crashes-per-driveway distribution are not approximately equal. For this reason, the negative binomial regression model is employed to identify driveway geometrics and roadway characteristics that affect driveway related crashes. The negative binomial model is shown in the equation below.

$$\ln \lambda_i = \beta X_i + \varepsilon_i$$

where:

- λ_i is the expected number of crashes for driveway *i*,
- X_i is a vector of explanatory variables,
- β is vector of estimable coefficients, and
- $\exp(\varepsilon_i)$ is a gamma-distributed error term with mean one and variance α .

The negative binomial estimation results of crashes per driveway are shown in Table 4.6. The model is based on data from 3774 driveways. The first column in the table shows the final model variables; they were obtained through a systematic evaluation and removal of variables with little to no impact on model performance. Column 2 shows the variables' estimated coefficients. A positive coefficient is interpreted as increasing crashes and a negative coefficient as decreasing crashes. The third column shows the standard errors for the regression coefficients. The last two columns show the z-values (test statistics) and p-values for null hypothesis that an individual predictor's regression coefficient is zero, given that the rest of the predictors are in the model. The results in Table 4.6 indicate that increasing the distance between driveways (D_Spacing), increasing the number of entry lanes (N_Entry_Ln), and having a raised median (RaisedMedian) will decrease driveway related crashes. Conversely, increasing driveway width (D_Width), corridor volume (Ln(AADT)) and corridor posted speed limit (SpeedLimit) will increase crashes. Similarly, a driveway with high turnover land use (D_Class5), a driveway with full access (as opposed to right-in right-out, FAorRIRO), and the presence of the nearby signalized intersection (D_Control) will increase crashes. The magnitude of the coefficients can be interpreted as follows. By having a raised median instead of other types of median, the difference in the logs of expected crashes will decrease by 0.7094, while holding the other variables in the model constant. In regard to the constant, it indicates that the expected number of crashes is nearly zero (actual value for λ_i is 3.2e-9; ln3.2e-9=-19.56). The p-values indicate that the variables D_Spacing, N_Entry_Ln, and SpeedLimit are not statistically significant at the 95% confidence level. Lastly, it is noted that the dispersion parameter for the negative binomial is 0.6134, which is significantly greater than 0, and thus, indicating that the negative binomial model is more suitable than the Poisson model for analyzing driveway crashes.

Table 4.6 Negative Binomial Estimation Results for Crashes per Driveway

Variables	Estimate	Std. Error	z-value	p-value
Intercept	-19.56	1.220	-16.038	< 2e-16
Driveway Spacing	-0.0004154	0.000281	-1.479	0.139233
Driveway Width	0.02656	0.002448	10.851	< 2e-16
Number of Entry Lanes	-0.3245	0.189	-1.814	0.069658
Raised Median	-0.7094	0.324	-2.191	0.028457
D_Class4 High Turnover	0.759	0.0925	8.386	<2e-16
D_Class5 High Turnover	0.8610	0.151	5.713	1.11e-08
Driveway Control	1.381	0.181	7.622	2.51e-14
Ln(AADT)	1.668	0.1058	15.771	< 2e-16
Speed Limit	0.01300	0.009735	1.335	0.1818
FA or RIRO	0.8114	0.239	3.484	0.000494

It is noteworthy that the analysis does not consider if a posted speed limit is the most appropriate speed limit considering geometric design of the facility and other factors. Also, the number of entry lanes variable is based on data that had either one or two entry lanes. None of the driveways along the 6 study corridors had more than two entry lanes.

4.4.2 **Development of Crash Modification Factors**

Crash modification factors (CMFs) capture the relationship between a change in a specific highway geometric design element (e.g., lane width) and safety. It is a multiplicative factor or function used to compute the expected number of crashes after implementing a given countermeasure at a specific site. Thus, given a CMF, this value would be multiplied by the expected crash frequency prior to treatment. A CMF greater than 1.0 indicates an expected increase in crashes, while a value less than 1.0 indicates an expected reduction in crashes after implementation of a given countermeasure. For example, a CMF of 0.9 indicates an expected safety benefit; specifically, a 10% expected reduction in crashes. On the other hand, a CMF of 1.1 indicates an expected degradation in safety; specifically, a 10% expected increase in crashes.

This study estimates the CMFs directly from the coefficients of the developed negative binomial model. The sample size is 3774 driveways. The method for developing CMFs is recommended by multiple publications for cross sectional studies (Stevens, 2008; Gross, 2010). This method has been used by Lord and Bonneson (2007) for estimating CMFs for rural frontage roads in Texas. Using their approach, the CMFs are estimated as follows.

$$CMF_j = e^{\left(\beta_j \times \left(x_j - y_j\right)\right)}$$

where:

- x_j = range of values or a specific value investigated (e.g., lane width, shoulder width, etc.) for CMF_j;
- y_j = baseline conditions or average conditions for the variable x_j (when needed or

available); and

- β_j = regression coefficient associated with the variable *j*.

This approach of estimating CMFs assumes that each model variable is independent and, thus, not influenced by the value of any other variable. It also assumes that the relationship between the change in the variable value and the change in crash frequency is exponential (as indicated by the negative binomial model). The following presents the derived crash modification factors/functions for relevant factors.

<u>Driveway Spacing</u>

$$CMF_{DS} = e^{(-0.0004154 \times (DS_a - DS_b))}$$

Where
  DS_a = driveway spacing in feet after modification.
  DS_b = driveway spacing in feet before modification.

As an example, increasing driveway spacing from 150 to 200 ft. would result in a CMF of 0.98 (a crash reduction of 2%). Decreasing driveway spacing 50 feet to 100 feet would result in a CMF of 1.02 (a crash increase of 2%). Figure 4.16 shows how the CMF changes with a corresponding change in driveway spacing.

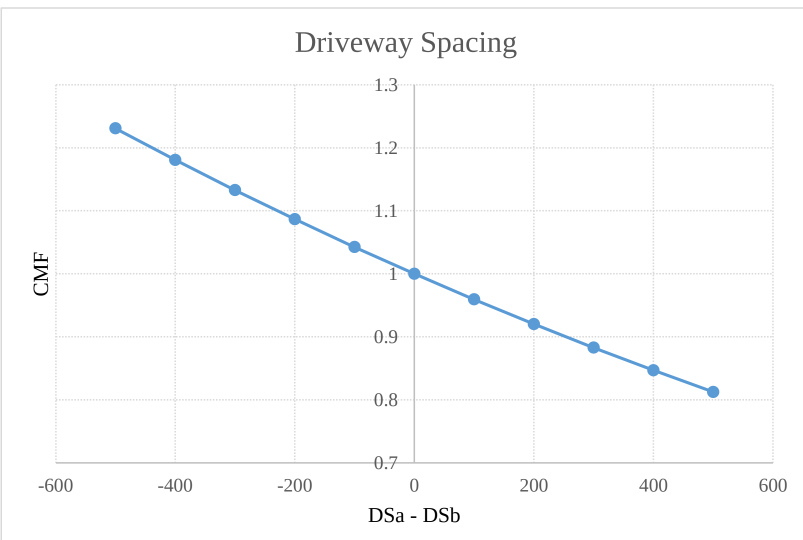


Figure 4.16: CMF vs Change in Driveway Spacing

<u>Driveway Width</u>

$$CMF_{DW} = e^{(-0.02656 \times (DW_a - DW_b))}$$

Where

DW_a = driveway width in feet after modification.
DW_b = driveway width in feet before modification.

The application of this CMF assumes that 24' is an ideal driveway width for 2 lane driveways or 12' for one lane driveways. This CMF suggests that increasing driveway width from the ideal width will increase the amount of driveway related crashes. It indicates that the use of continuous driveways should be avoided. This may be because of the increased conflict area associated with continuous driveways. As an example, reducing a 40 foot continuous driveway to a 24 foot typical 2 lane driveway *(DW_a-DW_b=-16)* will result in a crash reduction of 35%. Figure 4.17 shows a graph of how the CMF changes with a corresponding change in driveway width.

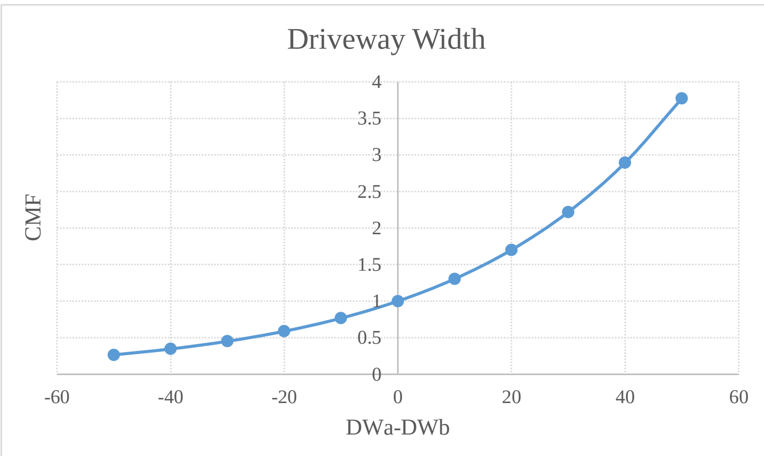


Figure 4.17: CMF vs Change in Driveway Width

Number of Entry Lanes

$$CMF_{NEL} = e^{(-0.341 \times [NEL-1])}$$

Where
NEL = Number of driveway entry lanes

For this CMF, the value 1 reflects the base, or typical number of driveway entry lanes. By definition, it is associated with a CMF value of 1.0. From the above equation, a driveway with 2 entry lanes would result in a CMF of 0.71 (a crash reduction of 29%). This can be attributed to drivers (those making left and right turns) having their own paths when entering the driveway thus reducing potential conflicts between two opposing drivers entering a driveway at the same time. All driveway data used for this model had either 1 or 2 entry lanes. Thus, the crash modification factors should only be calculated when going from 1 to 2 entry lanes or from 2 to 1 entry lanes.

Corridor Annual Average Daily Traffic

CMF$_{AATD}$ = $e^{(1.668 \times Ln(AADT_a - AADT_c))}$

Where
$AADT_a$ = Analysis Annual Average Daily Traffic
$AADT_c$ = Base or comparison Annual Average Daily Traffic

For this factor, the user can compute the CMF to compare the relative safety between two different AADT values. This factor is based on corridor volumes with an average AADT of 20,000 and thus should only be applied when the base AADT is close to this average. As an example, if the AADT increase from 20,000 to 25,000, then this increase in volume will result in a CMF of 1.51 (a crash increase of 51%). Figure 4 shows a graph of how the CMF changes with a corresponding increase in AADT assuming a base value of 20,000.

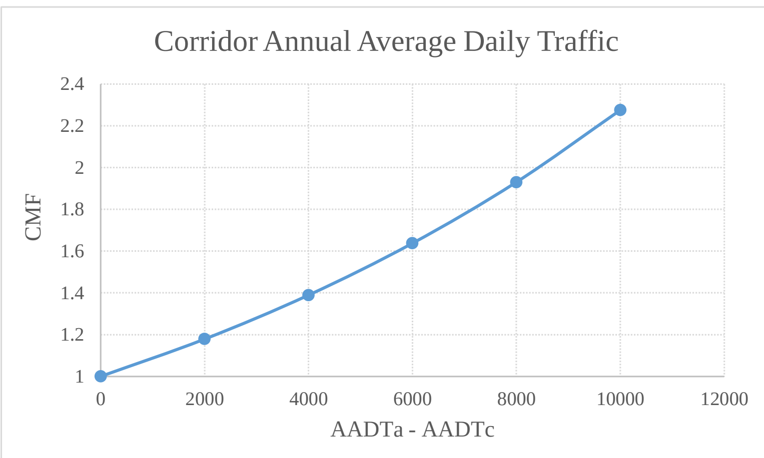


Figure 4.18: CMF vs Change in Corridor Annual Average Daily Traffic

CMFs for other base values can be interpolated from the safety performance function (SPF) shown in Figure 4.19 that shows the predicted number of crashes for different values of AADT if a driveway has 1 crash annually for an AADT of 20,000. This SPF is based on the negative binomial model presented earlier that is solved for different AADT values. The figure is not intended to predict the number of driveway crashes directly from AADT because different driveway characteristics are not considered. To determine a CMF from the SPF graph, identify the number of crashes for base and comparison AADT values. The CMF will be equal to the comparison number of crashes divided by the base number of crashes. As an example, if the base AADT is 10,000 and the comparison AADT is 15,000, the corresponding number of crashes per year is 0.031 and 0.062, respectively from the SPF. The corresponding CMF would equal to 0.062 crashes divided by 0.031 crashes which gives a CMF of 2.

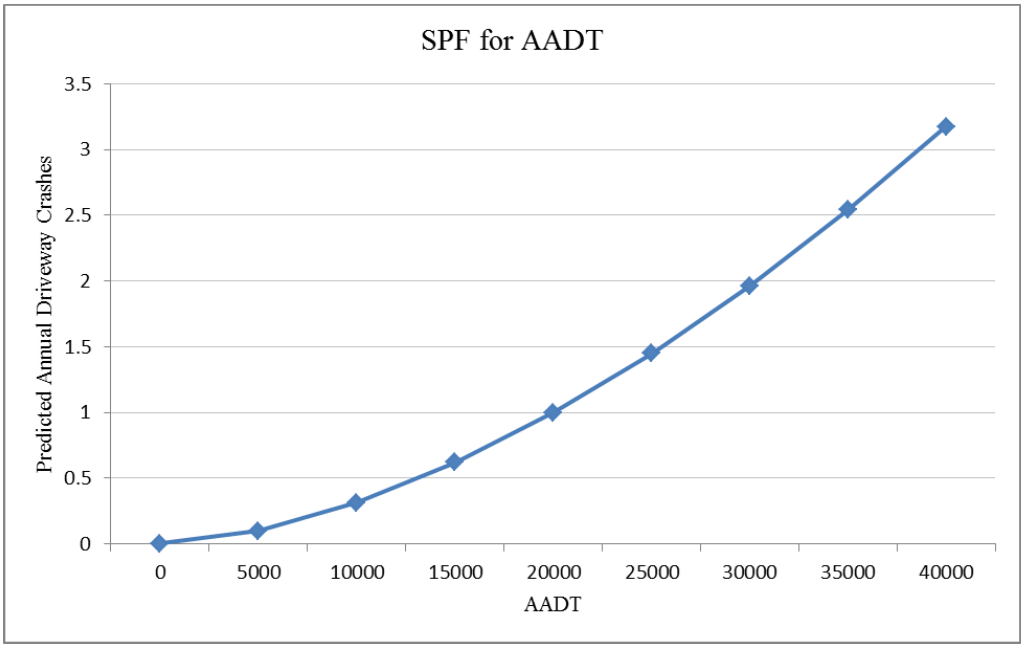


Figure 4.19: Driveway Safety Performance Function for AADT

Corridor Speed Limit

$CMF_{SL} = e^{(0.013 \times (SL_a - SL_b))}$

Where
SL_a = Posted Speed Limit of the travel way after
SL_b = Posted Speed Limit of the travel way before

Using an example, the average speed limit for the corridors was about 40 mph. Using this value as the base before value, if the speed limit was reduced to 30 mph would result in a CMF of 0.82 (a crash reduction of 18%). Increase the roadway speed from 40 mph to 55 mph result in a CMF of 1.35 (a crash increase of 35%). Figure 4.20 shows a graph of how the CMF changes with a corresponding change in speed limit. The range of speed limits for the six analysis corridors is between 30 and 55 mph.

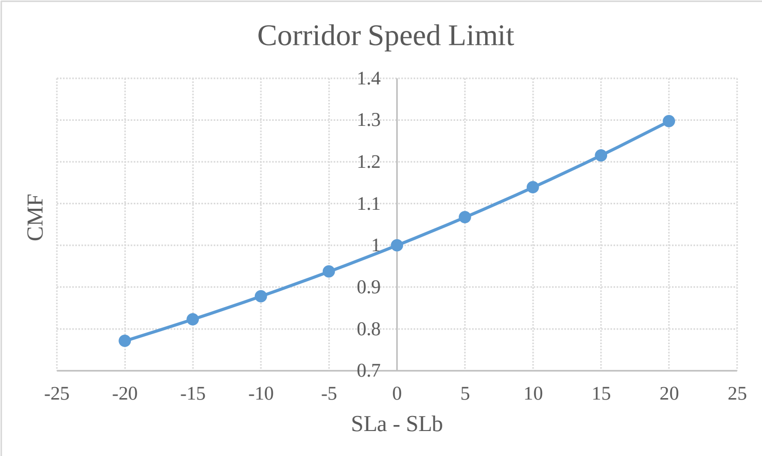


Figure 4.20: CMF vs Change in Corridor Speed Limit

Crash modification factors were also derived for non-continuous variables. They are presented in Table 4.7. The results indicate that installing a raised median (CMF=0.49) will reduce crash frequency by 51%. The CMF values from CMF Clearinghouse (see Chapter 2 and the Appendix) for this countermeasure range from 0.29 to 0.86. Thus, our finding is comparable to those found in other studies. Other results show that if driveways go from standard to high turnover driveways (Type 4 and 5), we can expect two times the amount of crashes of an average (medium land use) driveway. If the presence of a traffic signal is involved the expected crash rate increases up to four times the amount. This can be attributed to the higher driveway volumes in presence of a signal. When a right-in-right-out driveway is converted into a full access driveway, the crash rate would increase.

Table 4.7 Crash Modification Factors

Variables	**CMF**	**95% Confidence Bounds**	
Median (1 for raised, 0 for all others)	0.49	0	1.13
D_Class4 (High Turnover)	2.17	1.99	2.35
D_Class5 (High Turnover)	2.37	2.07	2.66
D_Control (Signalized)	3.98	3.62	4.33
FAorRIRO (Full Access or Right-in-right-out)	2.25	1.79	2.71

4.5 Safety Analysis of Intersection Corner Clearance

4.5.1 Overlay analysis

The research team conducted a detailed analysis of driveway crash data within 150 feet of intersections in which the corner clearance of the driveway does not comply with published standards in the SCDOT Access Management Guidelines. The corner clearance attribute from the GIS database of driveways for 6 corridors were used for this analysis as well as a 180 foot buffer of the intersection center point. Travelway polygons from the buffer analysis were also used and were overlaid with driveway buffer polygons that were within 150 feet of intersections and fell within 180 feet of the center point of the intersection. Buffering the intersection was necessary to identify if more than one driveway falls within 180 feet intersection buffer. The intersection buffer distance of 180 feet was used to account for the width of the intersection however only driveways with an actual corner clearance of 150 feet or less were included in the analysis. The resulting polygon layers were then overlaid with the crash data to determine the number of driveway related crashes within the overlapping hatched area shown in Figure 4.21. Note that the solution is the crashes that fall within the Boolean intersection (overlay) of buffers of three different features: 1) 180 foot intersection buffer, 2) travelway buffer, and 3) 50 foot driveway buffers with a corner clearance less than 150 feet.

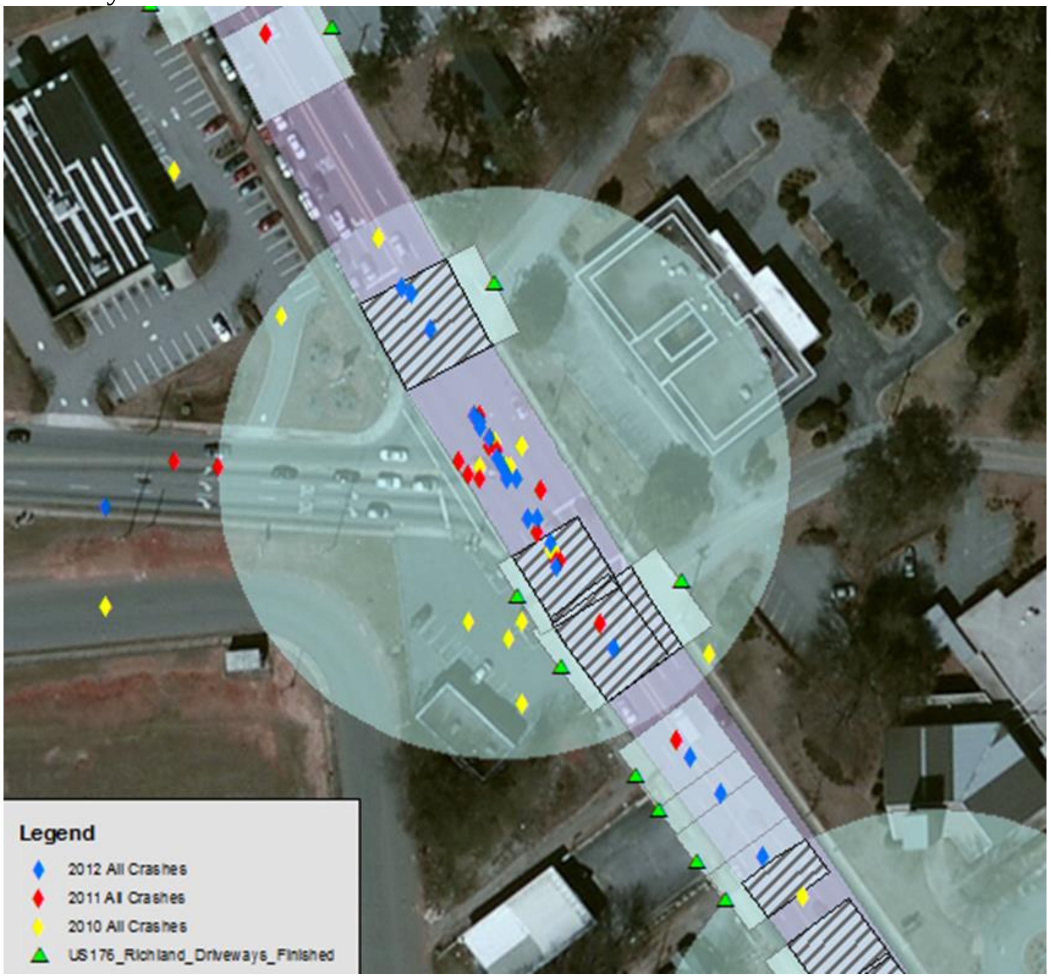


Figure 4.21 US 176 Richland Boolean Intersection Example

Three years of highway patrol crash data were used to compare crashes primarily geocoded by GPS (2010) with crashes primarily geocoded with SCCATTS (2011 and 2012). The number of crashes that fell within overlay totaled 129 crashes in 2010, and 510 crashes in 2012 (Table 4.8) for the 6 corridors. The total number of all driveway crashes along the corridors did increase by about 50% however the quantity of driveway crashes that occurred on the travelway in close proximity to intersections nearly quadrupled between from 2010 to 2012. While this increase is dramatic, it is due, in large part, to improved crash geocoding rather than a change in the actual number of crashes. A closer look at these locations (as seen in Figure 4.21) show that many of the 2010 crashes (yellow diamonds) occur outside of the travelway and thus are ignored by the GIS overlay operation. It was apparent from this analysis that the 2010 crash data results are misleading and indicate that these driveways (within the 150 foot corner clearance) are safer than they really are.

Table 4.8 Number of Driveways and Crashes Contained in Boolean Buffer Area

	# of driveways	**HP 2010 Crashes**	**HP 2011 Crashes**	**HP 2012 Crashes**
US 1 Richland	238	45	122	112
US 25 Greenville	188	24	136	169
SC 146 Greenville	53	14	51	75
US 176 Richland	117	26	69	74
SC 9 Spartanburg	100	12	38	58
US 17 Berkeley	113	8	35	37

Table 4.9 shows a comparison of the 2012 highway patrol crash data using two different distances: 1) from 0 to 150' from intersections; and 2) from 150' to 300' from intersections. All 6 corridors show that the number of driveway crashes within 150' of intersections is significantly higher than the number of driveway crashes between 150' and 300' from intersections. The crash rates are also higher in all but one case. It is interesting to note that there are more driveways that fall within the 150 corner clearance, which is not compliant with ARMS, versus the next 150 feet that is compliant.

Table 4.9 Comparison of driveway crashes occurring within 0-150 ft. and 150-300 ft. of an intersection

	# of driveways		**HP 2012 Crashes**		**Crash Rate**	
	0-150ft	**150-300ft**	**0-150ft**	**150-300ft**	**0-150ft**	**150-300ft**
US 1 Richland	238	124	112	32	0.47	0.26
US 25 Greenville	188	141	169	45	0.90	0.32
SC 146 Greenville	53	42	75	38	1.42	0.90
US 176 Richland	117	95	74	63	0.63	0.66
SC 9 Spartanburg	100	74	58	22	0.58	0.30
US 17 Berkeley	113	86	37	5	0.33	0.06

4.5.2 Negative Binomial Analysis of Corner Clearance data

The statistical analysis in section 4.4 as well as the literature review indicate that AADT is a significant contributor to crash incidence. Using the 2012 driveway crash data within 150' of intersections, a negative binomial model was generated relating crash incidence with AADT and the number of driveways within a corner clearance less than 150 feet. Figure 4.22 shows the safety performance function that resulted from the analysis. The figure shows the gradual increase in number of predicted crashes as the number of driveways and AADT increases. The figure also shows that the number of predicted crashes increases dramatically if more than one driveway falls within 150 feet of an intersection within the travelway. Driveway groupings were used in the analysis. The chosen groupings in terms of number of driveways with a corner clearance less than 150 feet of an intersection were "one or two", "three or four", "five or more" driveways. The figure indicates that the relationship is rising almost linearly for AADT values less than 10,000 and then begins to level off once volumes exceed 20,000 AADT.

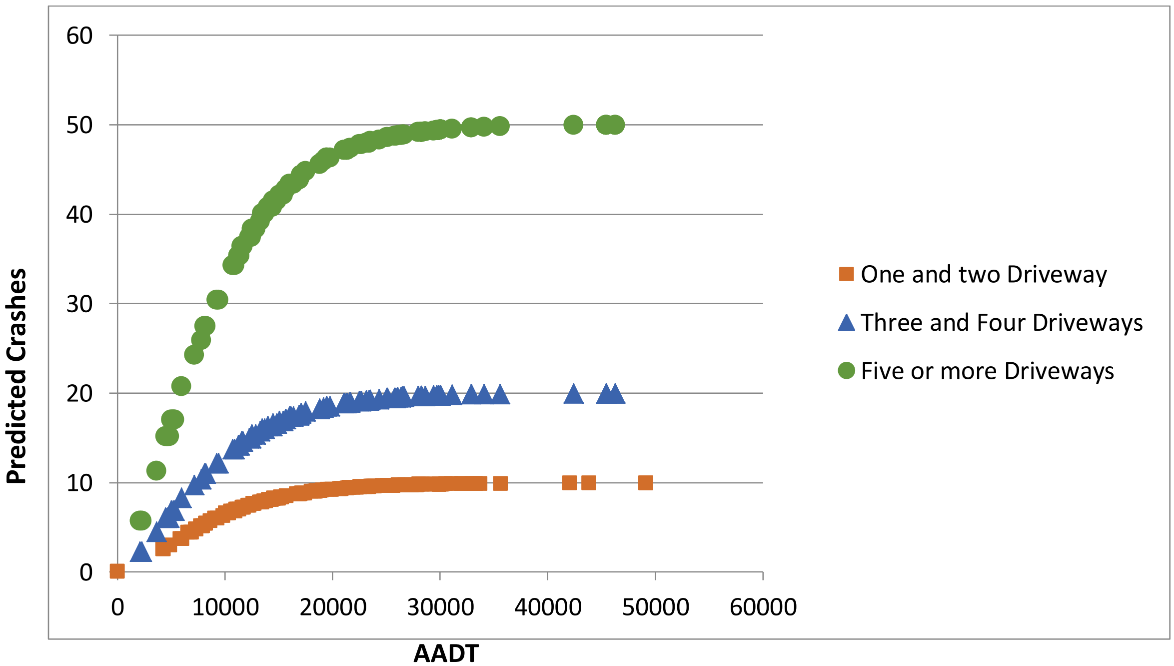
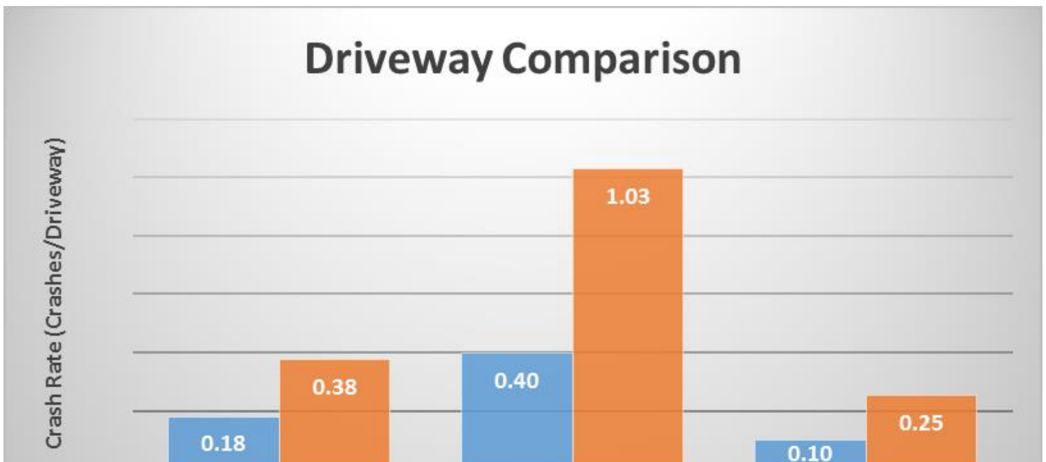


Figure 4.22 Predicted Crashes vs. AADT for driveways within the 150 ft. corner clearance

4.6 Safety Analysis of Medians and Right-In Right-Out Driveways

4.6.1 Right In Right Out Analysis based on land use

An additional analysis was conducted to compare the crash incidence of full access driveways with right-in right-out (RIRO) driveways for different types of land use (high vs. med/low). Figure 4.23 shows the resulting crash rates. While full access driveways show a crash incidence that is roughly twice that of RIRO driveways, this relationship is more than 2.5 times for high-turnover land uses. High-turnover land uses include gas stations, fast food restaurants, drive through banks, big box commercial, etc. Figure 4.24 compares the crash frequency of high-turnover land uses for full access driveways versus RIRO driveways. The figure shows the full access driveways with at least one crash in 2012 have a crash frequency that ranges from one crash up to 16 crashes. Nearly 90% of RIRO driveways that have at least one crash have either one or two crashes. None of the RIRO driveways have more than 6 crashes. Conversely, the figure shows that several of the full access driveways have more than ten crashes per buffer. One of the top driveways can be seen in Figure 4.25. This driveway is located in Greenville on a stretch of roadway with multiple intersections back to back to back. Another is shown in Figure 4.26 with a driveway literally entering into the intersection area.



	Overall	High Turnover	Mid to Low Turnover
RIRO	0.18	0.40	0.10
FA	0.38	1.03	0.25

Figure 4.23 Crash Rate/Driveway Comparison

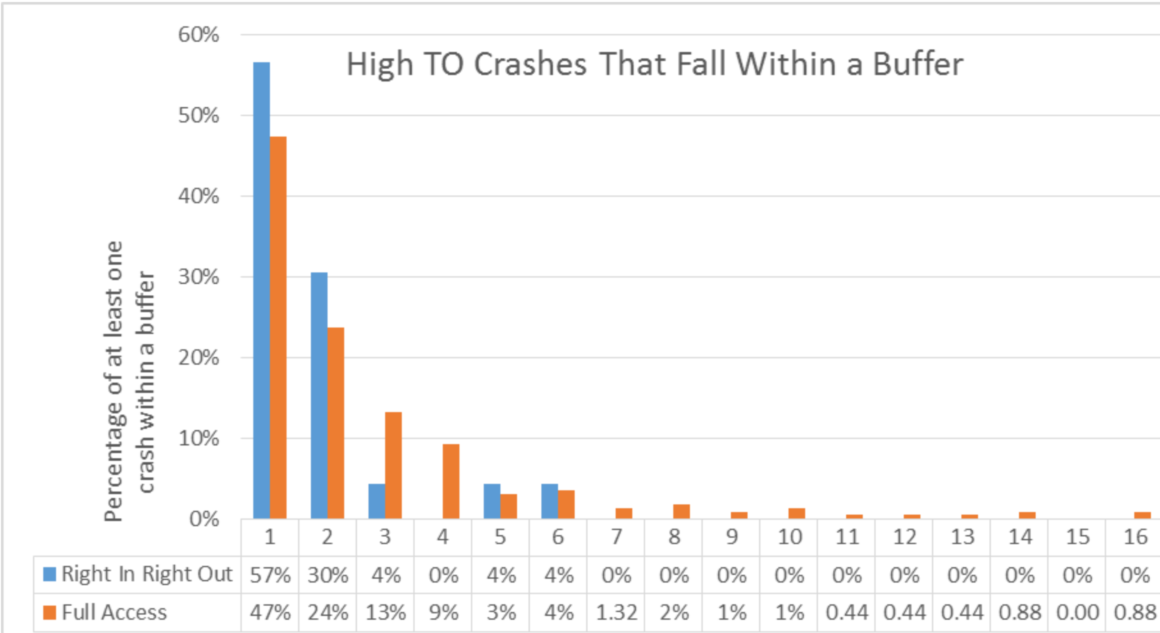


Figure 4.24 High Turnover Driveway Crash Frequency by Driveway Type (RIRO or Full Access)

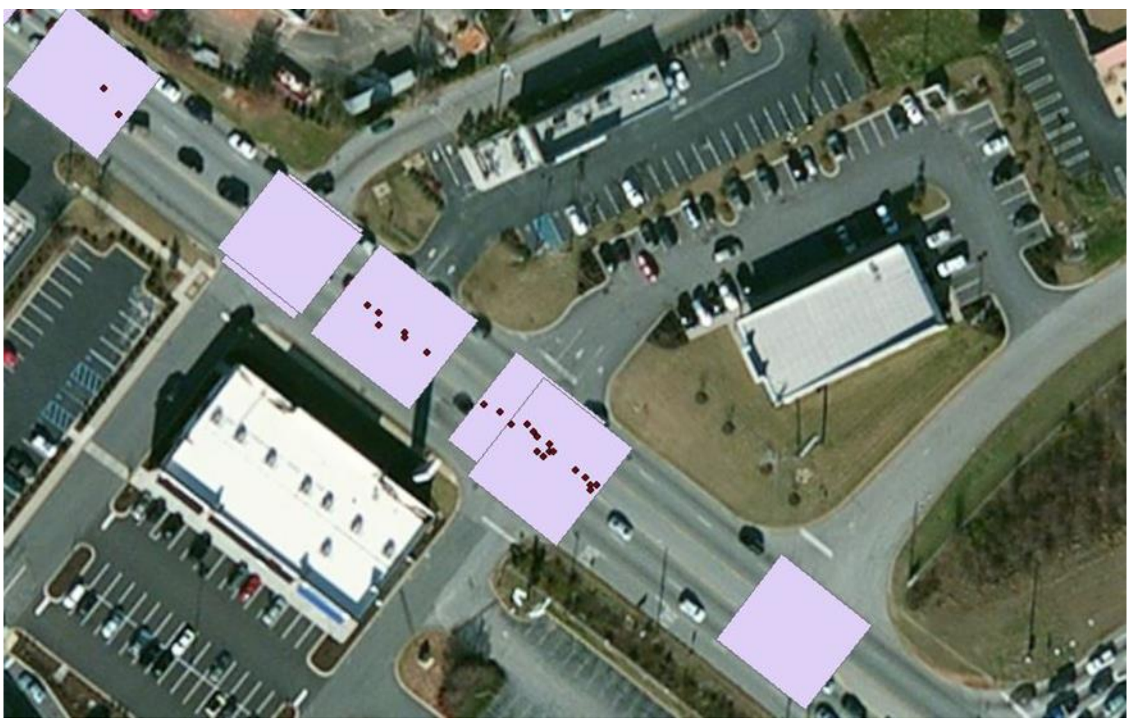


Figure 4.25 Busy, multi-driveway roadway

Figure 4.26 Driveway within intersection influence area

4.7 Safety Analysis Summary

The safety analysis highlighted a number of problems on major arterial roadways across SC. Many of these problems could have been avoided with strict adherence to the ARMS manual; however, it is noted that the manual was published after many of these driveways were permitted. Some of the more notable issues surround the number of driveways within a minimum 150 ft. corner clearance area, allowances for open driveways, and lack of median barriers at locations where left turns from driveways should be prohibited. Where these characteristics were found, there was also an increase in crash experience. Some access management practices that were shown to reduce crash experience include use of RIRO driveways, driveway entrance channelization, introduction of grassy or raised medians, increased spacing between driveways, situating driveways beyond the intersection influence area, reducing speeds along the corridor, and promoting multiple use driveways.

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CHAPTER 5: OPERATIONAL IMPACTS

5.1 Operational Analysis of Access Management

To date, many states have their own access management guidelines, many of which have been based on national standards but tailored to suit their states' needs and business practices. Driveway spacing is one of the key techniques used in access management. Since access points are one of key contributors to congestion, access spacing directly affects the traffic operations of roadways. Too many closely-spaced driveways increase delays and preclude effective traffic signal coordination. On the other hand, restricting driveway access may inhibit access altogether and/or over-concentrated traffic on those driveways that are permitted (TRB, 2013).

Different states have adopted a variety of driveway spacing policies in which the selected spacing is chosen based predominantly on characteristics of the adjacent roadway, such as type of roadway, access class, posted speed limit, and traffic volume. The different driveway spacing selection criteria found in the different state policies raise two important questions:

1. Are there any differences in safety performance across the various state DOT policies on minimum spacing?
2. Which roadway variables should be used in the driveway spacing selection process to improve safety?

Micro traffic simulators were extensively utilized in traffic operations analyses to assess the impacts of different traffic access management strategies on traffic operations (Chowdhury et al., 2005; Leng et al., 2008; Fang and Elefteriadou, 2005). In this chapter, operational performance of a typical corridor in South Carolina in terms of average speed and driveway spacing was investigated using the VISSIM traffic micro-simulator. Additional factors affecting operations such as effect of different driveway configuration, variation in driveway and mainline traffic demand, and corridor speed will be conducted in a follow-up research project sponsored by South Carolina Department of Transportation.

5.2 Operational Analysis Method

The analysis procedures are comprised of two key steps:

1. *Traffic network simulation and calibration:* Knox Abbott Drive located in West Columbia, South Carolina, was modeled using VISSIM. The model was then calibrated by comparing actual and simulated travel times to ensure that it reflects the real world traffic conditions.
2. *Average travel speed estimation:* To evaluate the effect of driveway density on corridor travel time, multiple simulation runs were performed to determine average travel time for three-driveway density scenarios defined in section 5.3.

5.2.1 Traffic Network Simulation and Calibration

5.2.2.1 Description of the study area

The first step of the methodology was to select the site and simulate the real traffic using VISSIM. Knox Abbott Drive in West Columbia, South Carolina was selected for this purpose due to the availability of travel time data on this corridor. In its current configuration, it represents a high driveway density of 30 driveways per mile. Knox Abbott Drive runs in an east-west direction, includes four signalized intersections, and extends approximately 1.8 miles with a posted speed limit of 35 mph (see Figure 5.1). It is a four-lane roadway with a center lane for two-way left turns with a relatively straight and flat alignment. The first signalized intersection in the system traveling westbound is Knox Abbott Drive at Axtell Drive. Axtell Drive consists of an exclusive right turn lane and a shared through left lane on the northbound approach and an exclusive left turn lane and a shared through right lane on the southbound approach. The second sequential signalized intersection in the system is Knox Abbott Drive at State Street. State Street consists of an exclusive left and right turn lane with two through lanes on the northbound approach and an exclusive left turn lane, through lane and a shared through right lane on the southbound approach. The third signalized intersection in the system traveling westbound is Knox Abbott Drive at Ninth Street. Ninth Street consists of an exclusive left turn lane and a shared through right lane on the northbound and southbound approaches. The fourth signalized intersection in the system on the westbound direction is Knox Abbott Drive at Twelfth Street. Twelfth Street consists of an exclusive left turn lane, a through lane, and a shared through right lane on the northbound and southbound approaches. The four signalized intersections are coordinated with a cycle length of 110 seconds. There is one un-signalized intersection in the study network, located at Knox Abbott Drive and Seventh Street. Seventh Street is a two-lane roadway and has a stop sign control at the intersection. Adjacent land uses include residential, retail, commercial and office. The major traffic generators along this corridor are restaurants, shopping malls, and office buildings, creating many driveways along both sides of Knox Abbott Drive.

Geometric, volume, travel time and control data were collected for the study site. All operational data were collected during the PM peak hours in March, 2013. Geometric data included intersection configuration, lane alignment, two-way left-turn lanes (TWLTLs), storage lanes, lane width, number of lanes, grades, driveway locations and distances. It is noted that the work of Dale and Woody was used to model TWLTLs in VISSIM (Dale and Woody, 2002). Traffic flow data for both roadways and driveways included traffic composition, volume counts by different movements, posted speed limit, and turn prohibitions. The traffic composition at the study site is 98% passenger cars and 2% heavy goods vehicles (HGV). Traffic control data included type of signals, cycle and phase settings, etc. Travel time data were collected using the test-car technique. The test-car travelled along Knox Abbott Drive between Twelfth Street and Axtell Drive during the peak hours (4-6 PM) 8 times in each direction during the green waves on Tuesday, March 12, 2013. The GPS data logger, Globalsat DG-100, was used to record the travel time for each run.

5.2.2. 2 Calibration of the Simulation Model

Once the VISSIM model was coded, it was calibrated by comparing the actual corridor average travel time (see Table 5.1) to the simulated average travel time obtained from 30 simulation runs of VISSIM. Each simulation run lasted 60 minutes, and data were collected after a 5 minute warm-up period. The travel time data were first confirmed to be normally distributed. Then, an F-test was used to compare the variances between actual and simulated travel times. It indicated that the difference in variances between the two samples was significant. Thus, a t-test (95% confidence interval) with unequal variances was performed to test the null hypothesis that the difference in the means of the simulated and actual travel times is zero. Table 5.1 shows the t-test results.

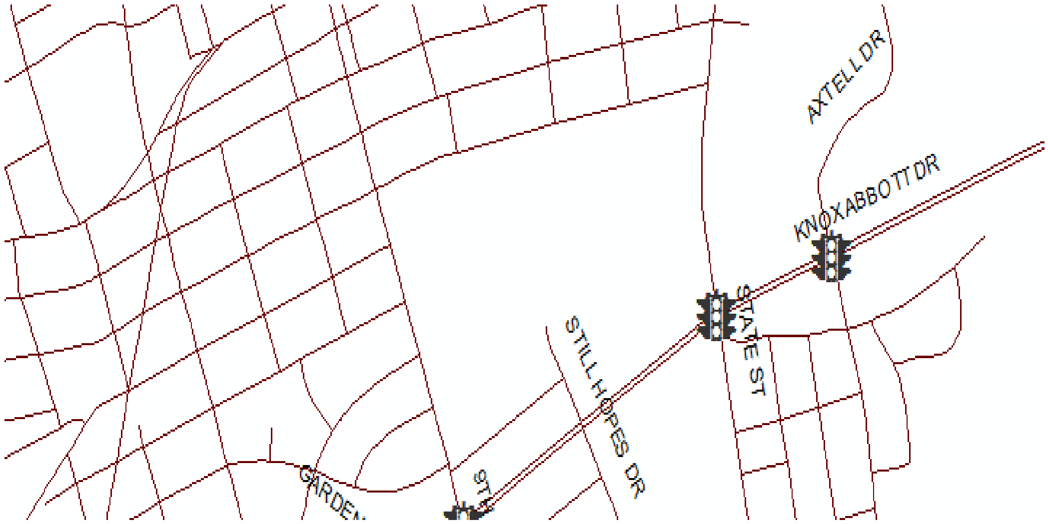

Figure 5.1 Knox Abbott Drive study corridor

Table 5.1 Comparison of actual vs. simulated travel times

	Mean	Variance	Sample Size	t_{stat}	$t_{critical}$	Sig.	Mean difference	Percentage difference
E-bound (Model)	119.85	3.29	30	1.22	2.36	NO	-5.90	-4.69%
E-bound (Field)	125.75	185.07	8					
W-bound (Model)	163.47	22.04	30	1.37	2.36	NO	6.34	4.04%
W-bound (Field)	157.13	164.98	8					

The t-test results indicated that the null hypothesis cannot be rejected. Thus, it can be concluded that the simulated network provides a reasonable traffic flow representation of the real world traffic. The calibrated study network was then used to estimate average travel time for three test scenarios representing various state policies for minimum driveway spacing.

5.2.2 Average travel speed estimation

Test scenarios were created in the aforementioned calibrated network with existing 35 mph speed limits, and minimum driveway spacing reflecting differences in selection criteria for three driveway spacing policies, discussed in following section 5.3. These scenarios were simulated using VISSIM. Two end-to-end travel time sections (eastbound and westbound) were created in the VISSIM network to collect travel time and average travel speed for different driveway spacing scenarios.

5.3 Operation impact assessment and Comparison

Three different minimum driveway spacing scenarios were assessed to determine their impacts on operational performance (i.e., average travel speed). The scenarios were chosen to represent selected state/city policies covering almost the range of minimum driveway spacing criteria currently used in the US. Since the minimum driveway spacing criteria required by some states are the same or similar (less than or equal to 5 feet), those states were grouped together and named as follows:

- Group 1 (G1): Georgia, Florida (City of Tallahassee), Ohio (OKI Regional Government, Cincinnati), New Jersey, West Virginia and Michigan (Ingham County)
- Group 2 (G2): Texas, Mississippi, Minnesota, Nevada, Indiana
- South Carolina (SC)

The minimum driveway spacing associated with each of the aforementioned groups is described in the following paragraphs.

- Group 1: States included in Group 1 have less restrictive minimum spacing guidelines than other states. The minimum spacing of driveways in Regulations for Driveway and Encroachment Control (Georgia) (GDOT, 2009), Manual on Rules and Regulations for Constructing Driveways on State Highway Rights-of-Way (West Virginia) (WVDOT, 2004), and State Highway Access Management Code, New Jersey Administrative Code (New Jersey) (NJDOT, 2012) are classified by posted speed limits and measured from center to center. For the speed limits, 35 mph, 40 mph, and 45 mph, the minimum spacing for driveways required by Georgia, West Virginia and New Jersey are 150 ft., 185 ft., and 230 ft., respectively. Those values are also applied by local governments in Florida (City of Tallahassee) (McGuirk and Satterly, 1976), Ohio (OKI Regional Government, Cincinnati) (ISU, 2013) and Michigan (Ingham County) (TRB, 1996).

- Group 2: According to the Access Management Manual, Version 2.0 (Mississippi) (MDOT, 2012) and Driveway Permit Manual (Indiana) (IDOT, 1996), with over 2000 AADT and over 50 peak hour trips on the roadway from commercial driveways, the minimum spacing for driveways for posted speed limits of 35 mph, 40 mph, 45 mph are 245 ft., 300 ft., and 350 ft., respectively. Access Management System and Standards (Nevada) (NDOT, 1999) classified spacing for non-signalized driveways based on 85th percentile speed. With the speed of 35 mph, 40 mph, 45 mph, the minimum driveway spacing required by Nevada is 250 ft., 300 ft. and 350 ft., respectively. Similarly, the Access Management Manual of Minnesota (MnDOT, 2008) and Access Management Manual of Texas (TXDOT, 2011) state that the spacing between driveways is the spacing between adjacent driveways as measured from the near edges of each driveway. For the speed limits, 35 mph, 40 mph, 45 mph, the minimum spacing of driveways required by Minnesota and Texas are 250 ft., 305 ft., and 360 ft., respectively. The driveways may be on the same side of the highway or on opposing sides of the highway.

- South Carolina: South Carolina has somewhat similar spacing criteria to group 2, however, was singled out for comparison purposes because the findings of this research may directly influence the next edition of the South Carolina Access and Roadside Management Standards (ARMS). The current ARMS manual prescribes minimum driveway spacing based on the posted speed limit, AADT of the adjacent roadway and peak hour trips generated by driveways (SCDOT, 2008). With AADT on the roadway over 2000 and driveways generating more than 50 peak hour trips, the minimum driveway spacing corresponding to posted speed limits of 35 mph, 40 mph, 45 mph are 220 ft., 275 ft., and 325 ft., respectively.

The minimum driveway spacing criteria required by the different states are summarized in Table 5.2. In this study, only scenarios with speed limit 35 mph were studied to compare operational performance of different driveway spacing standards.

Table 5.2 Minimum Driveway Spacing Required by Each State or Group of States

Speed (mph)	South Carolina (SC)	Group 1 (G1)	Group 2 (G2)
35	220	150	250
40	275	185	305
45	325	230	360

To assess the impact of minimum driveway spacing on traffic operations, scenarios with different driveway spacing were simulated and compared. The speed limits used in this study was 35 mph, the current posted speed limit on Knox Abbott Drive. Traffic volume was 500 vehicles per hour (vph) for each direction of Knox Abbott Drive. Driveways were added to or removed from both side of Knox Abbott Drive from State Street to 12th street (approximately 1.0 miles apart) to develop scenarios. The distance between two consecutive driveways is equal to the minimum driveway spacing required by each group. For the first and last driveway at the two ends of the network, their distances to their respective intersections follow the minimum corner clearances required by each group. The number of vehicles generated from each driveway was 20 vph. Vehicles exiting driveways in each scenario had the same percentage of left turns and right turn (50% each). The total number of vehicles entering each driveway was 20 vph. The network layout is shown in Figure 5.2.

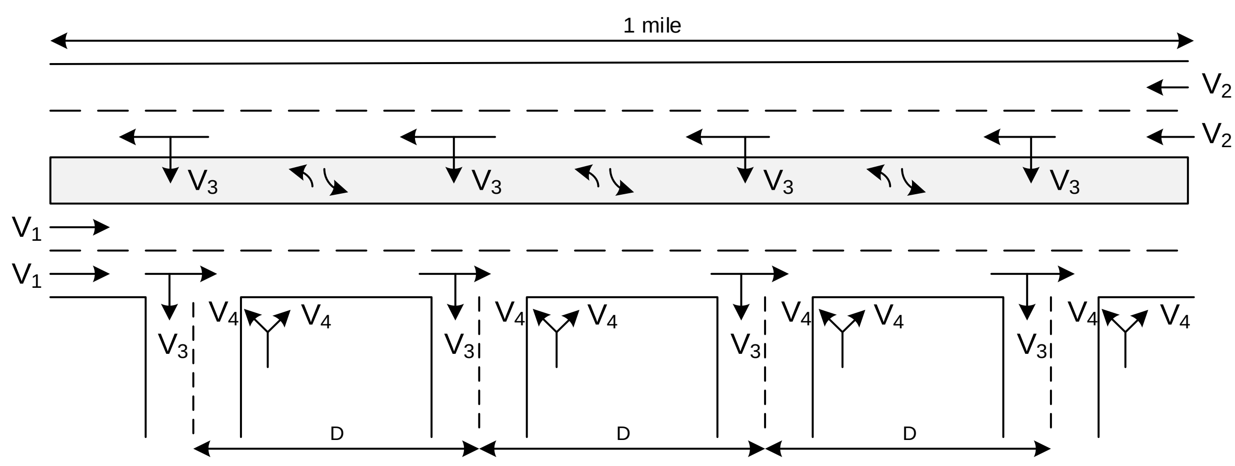

Figure 5.2 Simulated network layout

where, $\Sigma V_1 = \Sigma V_2 = 500$ vph, $V_3 = 10$ vph, $V_4 = 10$ vph

D: Minimum driveway spacing required by each state or group (ft.)

Each scenario was simulated 30 times with different random seed values in VISSIM and the duration of each simulation run was 1 hour which was deemed to be sufficient in capturing the stochastic nature of traffic flow and temporal variations in driving behavior. Each simulation run created a travel time file (.RSZ), which recorded average travel time and number of vehicles for each simulation step of 15 minutes. Using the travel time and travel time section length, average travel speed (mph) was calculated.

5.4 Results and discussion

Table 5.3 and Figure 5.3 show a summary of the average speed (mph) for different driveway spacing scenarios. Analysis results of three driveway spacing scenarios revealed that the average travel speed along the corridor was reduced with increased driveway density. Reduction in travel speed was the results of frequent conflicts between mainline traffic and driveway traffic (that enter and exit the driveways at relatively low speeds compared to mainline traffic speeds). In the three scenarios modeled in this study, group 1 had the highest driveway density and lowest average speed compared to the other two scenarios with lower driveway densities. This result corroborates findings reported in other studies (Gluck et al., 1999; Eisele and Frawley, 2004).

Table 5.3: Relationship between driveway density and average speed

Group	Driveway Density (# of driveways per mile)	Average Speed (mph)
SC- ARMS Standard	24	24.19
Group 1	35	23.90
Group 2	21	26.70

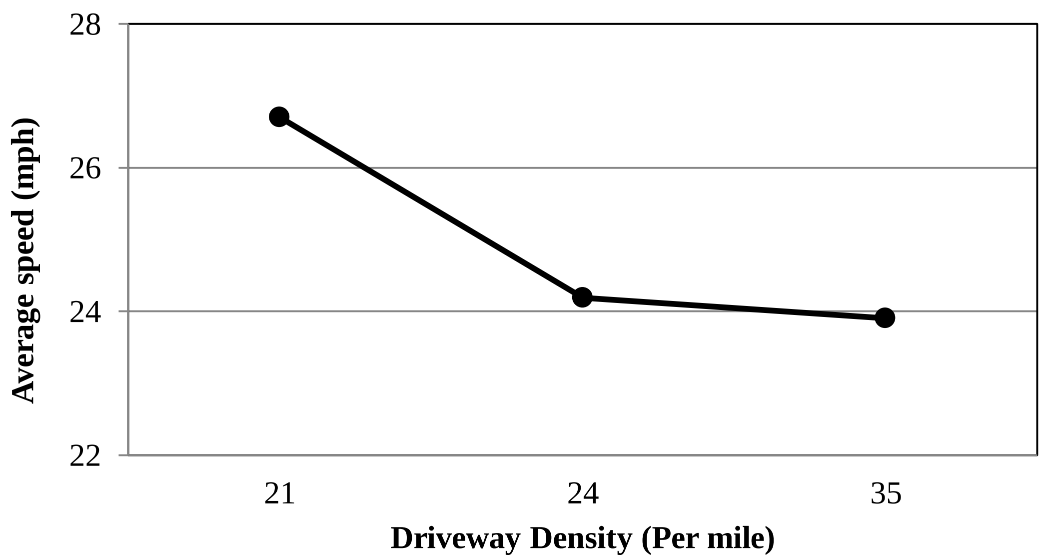

Figure 5.3 Relationship between driveway density and average speed

5.5 Summary

In current practice, states have adopted different minimum driveway spacing guidelines and these values are based on different criteria, such as volume on the adjacent roadway, trip generation from driveways, posted speed limit, land use, and access type. This study used VISSIM, a micro-simulation tool, to investigate the operational performance of different driveway spacing policies adopted by various DOTs in the US. Experimental results indicate that driveway spacing has direct influence on the average travel speed of a corridor. Since reduced driveway spacing negatively impact corridor travel speed, selection of a minimum spacing should consider its effect on the operational performance of the corridor. A follow-up research project sponsored by South Carolina Department of Transportation will investigate additional factors that impact operations, such as the effect of different driveway configuration, variation in driveway and mainline traffic volume, and corridor speed.

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CHAPTER 6: ECONOMIC IMPACTS OF ACCESS MANAGEMENT

Access management strategies control customer access to roadside businesses. Typically, there are less opposition from businesses about access control strategies for a new development; however, businesses often sees modification of existing access control as a negative factor for their businesses. Section 6.1 of this chapter summarizes the findings from previous studies about economic impacts of access management strategies. To quantify the economic savings by access management strategies, Section 6.2 presents a benefit-cost analysis of two different access modification strategies for a section of SC 146 corridor located in Greenville, South Carolina.

6.1 Literature review

While access management design for new developments may not elicit a strong reaction from developers, any changes to existing access control along a corridor or isolated location often receive intense reactions from nearby business owners. Usually, initial reactions are against access modifications, but these reactions tend to dampen over time (Vu et al., 2002). Similar findings have been reported in surveys conducted by Florida DOT and Iowa DOT (FDOT, 2012; Maze and Plazak, 1997). However, on several occasions, speculated negative economic impacts of access modification projects have resulted in lawsuits against transportation agencies. A Kansas study that analyzed lawsuits filed by 15 businesses against the Kansas Department of Transportation concluded that if new strategies did not require extreme circulation, businesses would not experience any negative impact; some would even experience positive growth (Rees et al., 2000). Transportation agencies subject to frequent lawsuits due to new access control initiatives along existing developments most often have to provide compensation based on the merit of claim judged by the court (Bainbridge, 2010).

The expected economic impacts of access management strategies depend on the type of strategies. A NCHRP report 254 concluded that left turn restrictions on driveways had a mix-perception from businesses, with some suspecting negative impacts while others expecting improvements in both congestion and traffic flow along a corridor (Weisbrod and Neuwirth, 1998). On the other hand, motorists had favorable view about access control improvement projects and perceived that access management make the corridor safer (City of Renton, 2005; FDOT, 2012). Impacts of access control are varied by type of businesses. Customers plan ahead of trips to "Destination businesses" such as electronic stores and salons, but they do not plan ahead of trips to "Drive-by businesses" such as gas stations (FHWA, 2006). Compared to drive-by businesses, destination businesses fared much better in terms of economic impact after the implementation of access control strategies. A FHWA report concluded that access control was not the sole arbiter in either a business success or failure (FHWA, 2006). A Texas study reported that gas stations (drive-by businesses) experienced a sales drop from restriction on direct left turns, while auto repair shops (destination businesses) saw an increase in business. Interestingly, most of the business owners stated that the quality of the product and service were more important than customer access (Eisele and Frawley, 1999).

There is also an inaccurate perception of property devaluation caused by access management projects. In one Texas study, the authors attempted to determine a decrease in property values caused by access improvement projects, and the authors found no such devaluation of those properties along the corridors where such projects had been completed (Eisele and Frawley, 1999). Similarly, a before-and-after analysis in Minnesota examined the impact of changing a corridor to a full access controlled freeway facility, and the study revealed that traffic flow along the corridor significantly increased and new businesses were attracted to the corridor. The authors also concluded that property value was mostly dependent upon the local economy, irrespective of access control to the properties (Plazak and Preston, 2005). Another similar study conducted in Kansas found no negative change in demand after limiting direct access, except for one drive-by business (Rees et al., 2000). Thus, perception by business owners are quite different from reality (Eisele and Frawley, 1999; Plazak and Preston, 2005).

A comprehensive economic analysis of how access management practices impact businesses is outside the scope of this study, which focuses on operational impacts; as such, data regarding business owners' perception/preference, property devaluation, economic losses, etc. were not collected. However, to examine the benefits of access management in terms of crash cost reductions a benefit-cost analysis is conducted.

6.2 Highway Safety Manual Analysis

To evaluate the benefits from crash savings and costs of implementing different access modification strategies, a 3.4 mile section of SC 146 (Woodruff Rd in Greenville, SC) between US 276 (Laurens Rd) and SC 564 (Garlington Rd) was selected. Land use along the corridor is heavily commercial. Existing lane configuration of the corridor includes two lanes in each direction with a two way left turn lane (TWLTL). Highway Safety Manual Part C procedures were used to predict crashes and determine expected crashes for the corridor. This analysis required the corridor to be broken into seven segments of varying in lengths, between 0.17 mile and 1.01 mile (Figure 6.1). The red dots in the figure represent the corresponding 9 intersections at the ends of the segments. There are actually 2 intersections at the end of segment 6 representing the two nodes at the interchange.

Tables 6.1 and 6.2 provide the total predicted, observed, and expected crashes for the segments and intersections in the analysis using data from 2011 and 2012. The predicted crash value represents typical crash performance from a statistical model derived from a group of similar sites. The observed crashes, highlighted in yellow, are the actual crash counts that were observed at the site for 2011 and 2012, respectively. The expected value is a weighted value that uses both the predicted and observed values and a weighting factor that takes into account the relative fit of the statistical model. Expected crashes have been adjusted to account for regression to the mean bias which occurs when sites are selected due to their overrepresentation of crashes. If the expected crashes are greater than the predicted, this indicates a potential for safety improvement at the site.

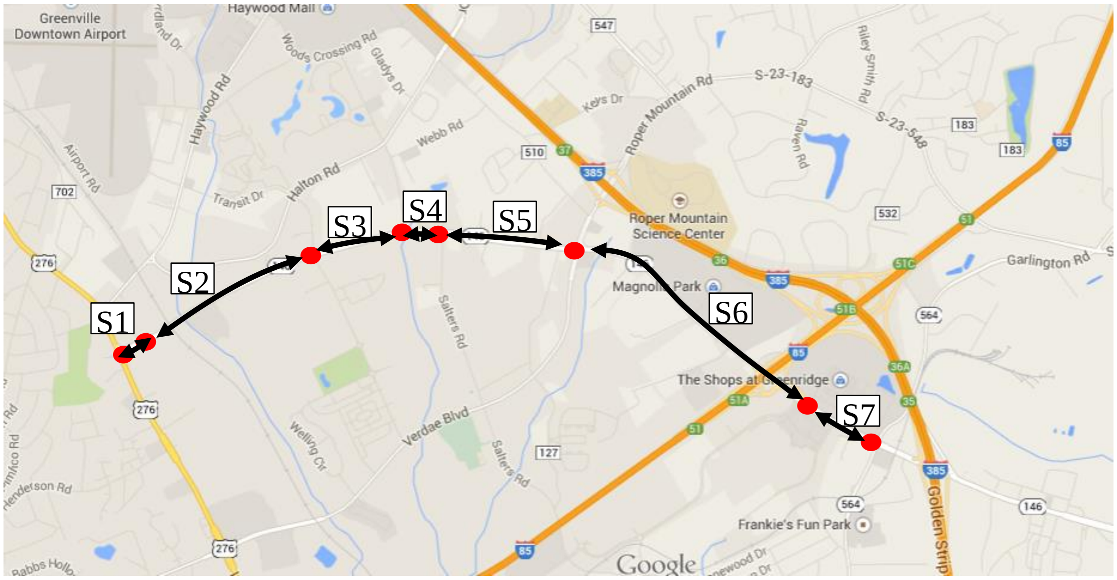

Figure 6.1 SC 146 Corridor and Segments

Table 6.1 2011 Predicted Crashes by Severity and Site Type and Observed Crashes Using the Site-Specific EB Method for Urban and Suburban Arterials

Collision type / Site type	Predicted average crash frequency (crashes/year)			Observed crashes, $N_{observed}$ (crashes/year)	Overdispersion Parameter, k	Weighted adjustment, w	Expected average crash frequency,
	$N_{predicted}$ (TOTAL)	$N_{predicted}$ (FI)	$N_{predicted}$ (PDO)			Equation A-5 from Part C Appendix	Equation A-4 from Part C Appendix
ROADWAY SEGMENTS							
Multiple-vehicle nondriveway							
Segment 1	0.843	0.232	0.611	0	0.810	0.594	0.501
Segment 2	2.548	0.700	1.848	1	0.810	0.326	1.505
Segment 3	1.379	0.379	1.000	0	0.810	0.472	0.651
Segment 4	0.600	0.165	0.435	0	0.810	0.673	0.404
Segment 5	1.687	0.464	1.224	0	0.810	0.423	0.713
Segment 6	4.304	1.183	3.121	18	0.810	0.223	14.947
Segment 7	1.541	0.424	1.118	0	0.810	0.445	0.685
Single-vehicle							
Segment 1	0.297	0.077	0.220	0	0.520	0.866	0.257
Segment 2	0.898	0.234	0.664	1	0.520	0.682	0.931
Segment 3	0.486	0.127	0.360	0.00	0.520	0.798	0.388
Segment 4	0.212	0.055	0.156	0	0.520	0.901	0.191
Segment 5	0.595	0.155	0.440	0	0.520	0.764	0.454
Segment 6	1.517	0.395	1.122	15	0.520	0.559	7.463
Segment 7	0.543	0.141	0.402	2	0.520	0.780	0.864
Multiple-vehicle driveway-related							
Segment 1	0.277	0.075	0.203	0	0.100	0.973	0.270
Segment 2	2.216	0.596	1.620	0	0.100	0.819	1.814
Segment 3	1.726	0.464	1.261	0.00	0.100	0.853	1.472
Segment 4	1.169	0.314	0.855	0.00	0.100	0.895	1.047
Segment 5	0.524	0.141	0.383	0.00	0.100	0.950	0.498
Segment 6	4.209	1.132	3.077	14.00	0.100	0.704	7.109
Segment 7	0.921	0.248	0.673	10	0.100	0.916	1.686
INTERSECTIONS							
Multiple-vehicle							
Intersection 1	5.501	1.911	3.590	23	0.390	0.318	17.437
Intersection 2	2.995	1.037	1.958	3	0.330	0.503	2.997
Intersection 3	6.016	2.071	3.944	0	0.390	0.299	1.798
Intersection 4	0.846	0.290	0.556	1	0.800	0.596	0.908
Intersection 5	1.852	0.578	1.275	0	0.390	0.581	1.075
Intersection 6	2.682	0.874	1.808	1	0.390	0.489	1.822
Intersection 7	1.009	0.399	0.610	0	0.330	0.750	0.757
Intersection 8	1.152	0.407	0.745	0	0.800	0.520	0.600
Intersection 9	0.365	0.144	0.221	0	0.800	0.774	0.283
Single-vehicle							
Intersection 1	0.294	0.068	0.226	0	0.360	0.904	0.266
Intersection 2	0.156	0.039	0.117	1	0.360	0.947	0.201
Intersection 3	0.331	0.078	0.253	0	0.360	0.894	0.296
Intersection 4	0.165	0.052	0.113	0	1.140	0.842	0.139
Intersection 5	0.146	0.044	0.103	0	0.360	0.950	0.139
Intersection 6	0.181	0.049	0.132	0	0.360	0.939	0.170
Intersection 7	0.093	0.024	0.069	0	0.360	0.967	0.090
Intersection 8	0.219	0.069	0.150	0	1.140	0.800	0.175
Intersection 9	0.064	0.021	0.043	0	1.140	0.932	0.059
COMBINED (sum	52.561	15.856	36.705	90	--	--	73.062

Table 6.2 2011 Predicted Crashes by Severity and Site Type and Observed Crashes Using the Site-Specific EB Method for Urban and Suburban Arterials

Collision type / Site type	Predicted average crash frequency (crashes/year)			Observed crashes, $N_{observed}$ (crashes/year)	Overdispersion Parameter, k	Weighted adjustment, w	Expected average crash frequency,
	$N_{predicted}$ (TOTAL)	$N_{predicted}$ (FI)	$N_{predicted}$ (PDO)			Equation A-5 from Part C Appendix	Equation A-4 from Part C Appendix
ROADWAY SEGMENTS							
Multiple-vehicle nondriveway							
Segment 1	0.843	0.232	0.611	0	0.810	0.594	0.501
Segment 2	2.548	0.700	1.848	0	0.810	0.326	0.832
Segment 3	1.379	0.379	1.000	1	0.810	0.472	1.179
Segment 4	0.600	0.165	0.435	0	0.810	0.673	0.404
Segment 5	1.687	0.464	1.224	2	0.810	0.423	1.868
Segment 6	4.304	1.183	3.121	38	0.810	0.223	30.488
Segment 7	1.541	0.424	1.118	1	0.810	0.445	1.241
Single-vehicle							
Segment 1	0.297	0.077	0.220	0	0.520	0.866	0.257
Segment 2	0.898	0.234	0.664	0	0.520	0.682	0.612
Segment 3	0.486	0.127	0.360	0	0.520	0.798	0.388
Segment 4	0.212	0.055	0.156	0	0.520	0.901	0.191
Segment 5	0.595	0.155	0.440	2	0.520	0.764	0.927
Segment 6	1.517	0.395	1.122	18	0.520	0.559	8.786
Segment 7	0.543	0.141	0.402	10	0.520	0.780	2.627
Multiple-vehicle driveway-related							
Segment 1	0.277	0.075	0.203	0	0.100	0.973	0.270
Segment 2	2.216	0.596	1.620	0	0.100	0.819	1.814
Segment 3	1.726	0.464	1.261	0	0.100	0.853	1.472
Segment 4	1.169	0.314	0.855	0	0.100	0.895	1.047
Segment 5	0.524	0.141	0.383	0	0.100	0.950	0.498
Segment 6	4.209	1.132	3.077	19	0.100	0.704	8.590
Segment 7	0.921	0.248	0.673	10	0.100	0.916	1.686
INTERSECTIONS							
Multiple-vehicle							
Intersection 1	5.607	1.951	3.655	19	0.390	0.314	14.797
Intersection 2	3.152	1.079	2.073	6	0.330	0.490	4.604
Intersection 3	6.016	2.071	3.944	6	0.390	0.299	6.005
Intersection 4	0.846	0.290	0.556	0	0.800	0.596	0.504
Intersection 5	1.852	0.578	1.275	2	0.390	0.581	1.914
Intersection 6	2.682	0.874	1.808	24	0.390	0.489	13.582
Intersection 7	1.009	0.399	0.610	1	0.330	0.750	1.007
Intersection 8	1.152	0.407	0.745	1	0.800	0.520	1.079
Intersection 9	0.365	0.144	0.221	1	0.800	0.774	0.509
Single-vehicle							
Intersection 1	0.298	0.069	0.229	0	0.360	0.903	0.269
Intersection 2	0.165	0.042	0.123	0	0.360	0.944	0.156
Intersection 3	0.331	0.078	0.253	0	0.360	0.894	0.296
Intersection 4	0.165	0.052	0.113	0	1.140	0.842	0.139
Intersection 5	0.146	0.044	0.103	0	0.360	0.950	0.139
Intersection 6	0.181	0.049	0.132	0	0.360	0.939	0.170
Intersection 7	0.093	0.024	0.069	0	0.360	0.967	0.090
Intersection 8	0.219	0.069	0.150	0	1.140	0.800	0.175
Intersection 9	0.064	0.021	0.043	0	1.140	0.932	0.059
COMBINED (sun	52.836	15.942	36.895	161.000	--	--	111.171

As shown in Table 6.1 and 6.2, the total predicted crashes for the corridor are 52.561 and 52.836. The minor difference is associated with a small increase in AADT from one year to the next. The actual observed crashes at the site; however, jump from 90 in 2011 to 161 in 2012. The weighted expected crash values reflect this jump, with 73 in 2011 and 111 in 2012. Thepredicted values were used in the cost benefit analysis because they represent a very modest scenario.

A cursory review of the observed crash patterns indicate that segments 6 and 7 and intersections 1 and 6 are all overrepresented in observed crashes. An aerial view of segment 6 can be found in Figure 6.2. It has extensive commercial development (Costco, Target, Home Depot, movie theatres, shopping mall, and numerous restaurants) with a continuous TWLTL. This segment did have the highest predicted crashes of all segments. The second highest in predicted crashes is segment 2; however, this segment does not have the observed crash experience of segment 6. In reviewing the segment, the driveways have much greater spacing, and few are opposite one another. There are also planted medians placed intermittently along this stretch that might discourage some left turn maneuvers as well as provide a traffic calming effect. All of these factors must be taken into account when defining safety strategies.

Figure 6.2 Segment 6 from MP 1.882 to MP 2.89 on SC 146 in Greenville

6.3 Benefit-cost Analysis

For this research, two access modifications were considered:

1) Converting the TWLTL to a raised median, and
2) Reducing number of driveways in each segment by 20%.

Given that these modifications only apply to segment crashes, the intersection crashes were removed from the following analysis.

Proposed access modification strategy 1: Convert TWLTL to a raised median

To reduce the number of crashes along the corridor, the current TWLTL could be converted to a raised median which would reduce conflicts between driveway traffic and through traffic, and consequently reduce the number of driveway related crashes. The expected reductions in number of crashes for the seven studied segments are summarized in Tables 6.3 to 6.9. The modification cost of a TWLTL to a raised median section was obtained from the SCDOT access management division. The reduction in the number of predicted crashes due to access modification was considered as the benefit, excluding economic impacts to roadside businesses. The average cost of a crash was calculated using the FHWA recommended crash cost values (FHWA, 2014) and the observed distribution of crash severity along the studied corridor for year 2011 and 2012. The benefit cost analysis for the seven segments showed a B/C ratio between 12 and 29, with an overall B/C ratio of 19 for the corridor. A B/C ratio of 19 means that every dollar spent on the raised median yields a return of $19 in crash savings.

Proposed access management strategy 2: Reduce driveway density

Driveway density is one of the primary factors often considered in corridor access management. Higher driveway density results in more crashes due to higher number of conflicts between the driveway traffic and the through traffic. In this proposed strategy, the driveway density is reduced by 20% for each segment. The expected reductions in the number of predicted crashes for the seven studied segments along Woodruff Road in Greenville are summarized in Tables 6.3 to 6.9. Refer to Figure 6.1 for the relative locations of each segment. The cost of implementing this strategy is primarily the cost of eliminating driveways to reduce potential conflict points. The cost of eliminating a driveway was obtained from SCDOT traffic engineering division. The benefit cost analysis of the seven studied segments showed a B/C ratio ranging from 83 to 367, with an overall B/C ratio of 255 for the corridor. As explained, A B/C ratio of 255 means that for every dollar spent on driveway reduction yields a return of $255 in crash savings. The higher B/C ratio of this strategy compared to strategy 1 is due to the fact that the cost of putting in raised medians is higher than the cost of eliminating driveways.

Table 6.3 Benefit-Cost Analysis (Segment 1)

Segment 1		
Median type	TWLTL	
Segment length (in miles)	0.23	
Number of Driveways	3	
Treatment type	Raised Median	Driveway Density (80% of existing)
Predicted number of crashes	1.40	1.40
Crash modification factor	0.43	0.93
Predicted number of crashes with treatment	0.60	1.3
Reduction in number of crashes	0.80	0.10
Crash savings (benefit)	$861,156	$107,644
Access modification cost	$71,300	$587
Benefit-cost (B/C) ratio	12	183

Table 6.4 Benefit-Cost Analysis (Segment 2)

Segment 2		
Median type	TWLTL	
Segment length (in miles)	0.64	
Number of Driveways	17	
Treatment type	Raised Median	Driveway Density (80% of existing)
Predicted number of crashes	5.80	5.80
Crash modification factor	0.38	0.93
Predicted number of crashes with treatment	2.20	5.4
Reduction in number of crashes	3.60	0.40
Crash savings (benefit)	$3,875,200	$430,578
Access modification cost	$198,400	$1,761
Benefit-cost (B/C) ratio	20	244

Table 6.5 Benefit-Cost Analysis (Segment 3)

Segment 3		
Median type	TWLTL	
Segment length (in miles)	0.38	
Number of Driveways	14	
Treatment type	Raised Median	Driveway Density (80% of existing)
Predicted number of crashes	3.70	3.70
crash modification factor	0.32	0.84
Predicted no. of crashes with treatment	1.20	3.1
Reduction in number of crashes	2.50	0.60
Crash savings (benefit)	$2,691,111	$645,867
Access modification cost	$117,800	$1,761
Benefit-cost (B/C) ratio	23	367

Table 6.6 Benefit-Cost Analysis (Segment 4)

Segment 4		
Median type	TWLTL	
Segment length (in miles)	0.17	
Number of Driveways	12	
Treatment type	Raised Median	Driveway Density (80% of existing)
Predicted number of crashes	2.00	2.00
Crash modification factor	0.30	0.90
Predicted no. of crashes with treatment	0.60	1.8
Reduction in number of crashes	1.40	0.20
Crash savings (benefit)	$1,507,022	$215,289
Access modification cost	$52,700	$1,174
Benefit-cost (B/C) ratio	29	183

Table 6.7 Benefit-Cost Analysis (Segment 5)

Segment 5		
Median type	TWLTL	
Segment length (in miles)	0.46	
Number of Driveways	4	
Treatment type	Raised Median	Driveway Density (80% of existing)
Predicted number of crashes	2.90	2.90
Crash modification factor	0.38	0.97
Predicted no. of crashes with treatment	1.10	2.8
Reduction in number of crashes	1.80	0.10
Crash savings (benefit)	$1,937,600	$107,644
Access modification cost	$142,600	$587
Benefit-cost (B/C) ratio	14	183

Table 6.8 Benefit-Cost Analysis (Segment 6)

Segment 6		
Median type	TWLTL	
Segment length (in miles)	1.01	
Number of Driveways	33	
Treatment type	Raised Median	Driveway Density (80% of existing)
Predicted number of crashes	10.40	10.40
Crash modification factor	0.38	0.90
Predicted number of crashes with treatment	4.00	9.4
Reduction in number of crashes	6.40	1.00
Crash savings (benefit)	$6,889,244	$1,076,444
Access modification cost	$313,100	$4,110
Benefit-cost (B/C) ratio	22	262

Table 6.9 Benefit-Cost Analysis (Segment 7)

Segment 7		
Median type	TWLTL	
Segment length (in miles)	0.41	
Number of Driveways	7	
Treatment type	Raised Median	Driveway Density (80% of existing)
Predicted number of crashes	3.10	3.10
Crash modification factor	0.35	0.97
Predicted number of crashes with treatment	1.10	3.00
Reduction in number of crashes	2.00	0.10
Crash savings (benefit)	$2,152,889	$107,644
Access modification cost	$127,100	$587
Benefit-cost (B/C) ratio	17	183

6.4 Summary

Benefit-cost analyses of two different access modification strategies following the Highway Safety Manual (HSM) procedures suggest that it is beneficial to convert a TWLTL to a raised median. Similarly, it is beneficial to reduce the driveway density on a corridor. The HSM analysis used in this study only considered safety benefits of access management strategies. It did not consider the impact of different access management strategies on surrounding businesses. A follow-up research project sponsored by South Carolina Department of Transportation will investigate these aspects in detail.

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CHAPTER 7: RECOMMENDATIONS FOR SCDOT ARMS, ACCESS AND ROADSIDE MANAGEMENT STANDARDS

7.1 Overview of Recommended SCDOT ARMS Improvements

Access to commercial and residential properties, access/driveway design standards, and appropriate incorporation with the surrounding roadway network comprise complex interrelated traffic flow characteristics. Achieving an optimal balance between these factors has a considerable impact on traffic operation and traffic safety. These access and mobility factors are crucially important to the public when traveling along thoroughfares and entering/exiting adjacent properties and businesses.

Based on findings from the research, comparisons with the current guidelines and literature review from other state DOT's, a series of proposed changes and modifications are identified for the SCDOT Access and Roadside Management Standards (ARMS). An important finding from the literature review pertaining to current practices at other agencies is that ARMS currently requires application of appropriate access policies and corresponding design standards. Problems primarily result when property owners and land developers circumvent standard adherence to access standards through misuse of the current waiver process resulting in variances from adopted design standards. As SCDOT plans to revise and republish ARMS, it is important for the updated document to include a concentrated emphasis on SCDOT sponsored research findings, quantifying tangible safety benefits that support consistent use of best polices and practices for access design. Additionally, conditional stipulations should be adopted clearly identifying surroundings, locations, land uses, and site configurations where adherence to minimum adopted standards is crucially important to avoiding occurrence of higher crash rates, and furthermore, limiting exceptions in the form of waivers that will only be considered under extraordinary circumstances.

As described in this report, access related SCDOT sponsored research includes evaluation and analysis of a variety of driveway and access design attributes. Since crashes are random and result from a variety of factors, it is critically important that access design configurations for proposed developments minimize crash related variables whenever possible. To successfully evaluate where and how driveway access is permitted, the encroachment application process should be rigorous and extensive, with applicants proposing and requesting approval for safe and efficiently designed access connections that are engineered to best mitigate access-related crashes identified in this this report, as SCDOT sponsored research findings.

As appropriate access design standards and policies are already delineated and required in the current version of SCDOT ARMS, improvement recommendations will: 1.) Focus on suggested additional contextual material emphasizing safety and crash related factors, 2.) Inclusion of SCDOT sponsored research findings on crash data that augment specific access design standards and requirements, and 3.) Include the addition of stipulations and conditions emphasizing the need to adhere to minimum required design standards for certain locations, land uses, and site configurations where crash related issues are identified as considerable concern as determined from SCDOT sponsored research findings.

Summary of Access Management Best Practices from other Agencies

The literature review provided in Chapter 2 summarizes beneficial operational and safety outcomes from access management strategies and policies implemented around the U.S. and abroad. Evidence-based findings from analysis of crash data along representative South Carolina arterial highway corridors supports measureable safety improvements resulting from application of access management policies, standards, and guidelines. The following contextual information should be considered for inclusion in an updated SCDOT ARMS document as a summary of best access management practices from other agencies includes:

Raised Medians – Utah DOT determined that raised medians reduce the frequency of crashes by 39 % and reduce the frequency of severe crashes by 44 % (Schultz, Lewis, 2006). Missouri DOT recommends raised medians when the projected AADT is greater than 28,000 vehicles per day or there are more than 24 commercial driveways per mile (Missouri DOT, 2006).

Right-in/Right-out Driveways – Right-in/right-out driveways in Ohio were used to reduce conflicts from 9 to 2 by eliminating left-in and left-out movements. Research indicates the majority of crashes at driveways involve left turning vehicles and eliminating these movements significantly reduces the potential for crashes.

Traffic Impact Studies – Colorado requires submittal of a traffic impact study for access permits generating a design hour volume of 100 vehicles or more.

Left Turn Lanes – Installation of a left-turn and right-turn lanes are considered at an existing access point that does not have turn lanes when an average of 4 crashes per year has occurred over the previous five-year period.

Intersection Corner Spacing – Iowa DOT requires a minimum corner spacing distance of 150 feet from adjacent intersection centerline for driveways with less than 2,500 vehicles per day and a minimum corner spacing distance of 300 feet for driveways with greater than 2,500 vehicles per day (Iowa DOT, 2012). Minnesota DOT requires driveways to be located as far as possible on the parcel away from an adjacent intersection, with use of a shared driveways, right-in/right out driveways with a raised median, or use of side street driveways whenever practical (Minnesota DOT, 2008).

Access Management Database System – Oregon DOT uses a statewide access management database system called CHAMPS (Central Highway Approach/Maintenance Permit System) to track applications, permits, approvals, inspections, and generate official correspondence to applicants (Oregon DOT, 2006). CHAMPS can also produce summary statistics by category, location, or facility type providing useful data aggregations helpful in management level decision-making and broad policy assessments.

Shared Driveways – Shared driveways have a variety of safety/operational benefits including reducing the number of driveways, increasing driveway spacing, minimizing conflict points on the arterial roadway, providing cross access between properties/parcels and improve site circulation patterns. Florida DOT uses shared driveways as a very beneficial access for corner parcels and when applied in lieu of individual adjacent driveways, are helpful in improving visibility for driveway traffic (Florida DOT, 2008). In addition, for roadways serving higher volumes of through traffic, shared driveways used in combination with other access management features, preserve arterial roadway traffic function for improved mobility.

Influence of Access Management Best Practices on Safety

Consistent application of access management best practices and adopted design techniques produce many beneficial outcomes for the traveling public including reduced crashes, fewer vehicle conflicts and improved movement of traffic. Implementation of effective access management applications has produced 25-31 percent reduction in severe crashes along urban/suburban arterials (Highway Safety Manual, 2010). Benefits of access management that can be realized in communities with effective polices and practices include improving roadway safety conditions, promoting properly designed access and circulation patterns, and proving property owners, employees and business patrons, with safe access to roadways (Texas DOT, 2011). Research results showed that access management features have a a significant impact on safety with raised medians lowering crash rates in comparison to two-way let turn lanes by 23 percent and additionally for raised median roadway sections, additional median openings result in 4.7 percent increase in total crash rate (Magua, Kaseko, 2014).

Sample Access Wavier Application Forms

Essentially all state DOT access management policies and driveway application procedures allow for the consideration of waivers from best practices. The Kentucky Transportation Cabinet categorizes access waiver variances into two designation levels, minor and major deviations. The designated level determines the amount of information that must be submitted and the extent of rigor required to render a decision engaging multiple departments within the agency. Oregon DOT allows access design decisions to be appealed through a formal three-step appeal process that includes: 1.) Post-decision collaborative discussion, 2.) Review by a Dispute Review Board, and 3.) Contested case hearing at the Office of Administrative Hearings. Links to sample access waiver application forms and procedures from other State DOT's are provided below:

Oregon DOT	http://www.oregon.gov/ODOT/HWY/ACCESSMGT/Pages/index.aspx
Florida DOT	http://www2.dot.state.fl.us/proceduraldocuments/forms/byofficedetail.asp?office=SYSTEMS+PLANNING+OFFICE
Colorado DOT	https://www.codot.gov/business/permits/accesspermits
Kentucky TC	http://transportation.ky.gov/Congestion-Toolbox/Documents/KTC%20Access%20Management%20Report.pdf

7.2 Recommended Modifications to Existing or Planned Updated SCDOT ARMS

The South Carolina Access and Roadside Management Standards (ARMS) provide criteria and guidelines needed for access encroachments connecting with SCDOT right-of-way. ARMS was most recently published in 2008 and is accompanied by several years of subsequent errata sheets. Improvements to ARMS standards would be useful in a continued effort to reduce crashes, injuries, and fatalities on South Carolina roads related to adjacent site and development access. Of particular concern are access waivers that are granted in cases of undue hardship caused by strict adherence to the ARMS (Chapter 1, Section 1E). Based on research findings, examination of best practices from other agencies, and a detailed review of the ARMS standards, specific changes and modifications to the SCDOT ARMS are summarized in Table 7.1. Changes and modifications are presented under subject headings to allow incorporation of these suggested improvements into either an updated SCDOT ARMS or revision of the existing document via citation of specific chapter, section and page in the current section of ARMS. Additionally, sponsored SCDOT research findings are cited to further support suggested revisions and adherence to required access design standards.

Table 7.1: Proposed SCDOT ARMS Changes and Modifications

Subject/Type Change	Proposed Modification	ARMS 2008: Chapter, Section, Page
Research Summary Add summary table for SCDOT sponsored research	Insert a table to summarize driveway categories, evaluation factors, and crash rates ranges determined from SCDOT sponsored research	Ch. 1, Sec. 1A-3, pg. 6
Waiver Stipulation Insert an additional item regarding safety importance and requirements	Requested access waivers shall be evaluated and designed so as to not have an adverse effect on safety and shall be configured to include design elements helpful in mitigating increased crash rates as identified in SCDOT ARMS	Ch. 1, Sec. 1E-2, pg. 12
Safety Stipulation Insert discussion regarding safety and crash rates	Location and design of site access, circulation and driveways can have a considerable impact on crash rates. Access should be configured with consideration for safe ingress/egress and configured to include deign elements helpful in mitigating increased crash rates as identified in SCDOT ARMS	Ch. 2, Sec. 2D-1, pg. 15
Driveway Classification Provide reference to crash rate results from SCDOT sponsored research	Provision of appropriate driveway design features and adherence to design standards are crucially important for medium, high and major volume driveways, as these classifications experience much higher crash rates per findings from SCDOT sponsored research shown in Figure 4.10. Table 4.7 indicates the number of driveway crashes for high-turnover land uses are more than double that of most other land uses.	Ch. 3, Sec. 3A-1, pg. 20
Driveway Classification Expand list of driveway design features	**High Volume:** Typically designed with high volume features such as radial returns, turn lanes, right-in, right-out only driveways with raised islands to prevent far-side access, shared driveways, full access on minor or side street roadway, and dual entrance lanes for full access driveways. **Major Volume:** Designed with high volume features including radial returns, turn lanes, medians, right-in, right-out only driveways with raised islands to prevent far-side access, shared driveways, full access on minor, side or rear street roadway, and dual entrance lanes for full access driveways.	Ch. 3, Sec. 3A-1, Tb. 3-3, Pg. 20
Driveway Classification Add contextual information on safety and design, in text and/or as Table footnote	Determination of driveway design features should include engineering consideration of the following: 1. Shared driveways are highly encouraged. 2. Right-in, right-out only driveways are highly encouraged along major roadways, with full access driveways to the proposed site development provided on minor or side street roadways. 3. SCDOT sponsored research findings clearly show that access design, spacing and density for driveways have a considerable	Ch. 3, Sec. 3A-1, Tb. 3-3, Pg. 20

	impact on safety and crash rates. 4. Only in extraordinary circumstances shall the RE consider exception, via access waivers, to access/driveway design standards for higher volume roadways or medium to major volume driveways.	
Driveway Design Elements Provide reference to crash rate results from SCDOT sponsored research	Selection of appropriate driveway geometric features, adherence to required dimension standards, and provision of optimal lane configurations are crucially important elements for driveway access design, as these factors have a considerable effect on safety and crash rates per findings from SCDOT sponsored research shown in Figures 4.12, 4.14,4.15, 4.17, and Table 4.7.	Ch. 3, Sec. 3B, pg. 20
Driveway Design Elements – Corridor AADT Provide reference to crash rate results from SCDOT sponsored research	Corridor Annual Average Daily Traffic (AADT) is an important consideration in the selection of appropriate driveway geometric features, adherence to required dimension standards, and provision of optimal lane configurations, as this factors has a considerable effect on safety and crash rates per findings from SCDOT sponsored research shown in Figures 4.18 and 4.19.	Ch. 3, Sec. 3B, pg. 20
Driveway Design Elements – Corridor Speed Limit Provide reference to crash rate results from SCDOT sponsored research	Corridor Speed Limit is an important consideration in the selection of appropriate driveway geometric features, adherence to required dimension standards, and provision of optimal lane configurations, as this factors has a considerable effect on safety and crash rates per findings from SCDOT sponsored research shown in Figure 4.20.	Ch. 3, Sec. 3B, pg. 20
Driveway Design Dimensions Add contextual information on safety and design, in text and/or in Figure footnote	Determination of critical dimensions in driveway design should include engineering consideration of the following: 1. Shared driveways are highly encouraged. 2. Dual entrance lanes configured separately for right turn in and left turn in should be considered for high and major volume driveways as SCDOT sponsored research findings clearly show higher crash rates result for these driveway classifications when only a single entrance lane is provided. 3. Access designs including continuous driveways or mountable curbs shall be avoided as increased conflict areas are created and SCDOT sponsored research findings clearly show high crash rates result from these configurations. 4. Right-in, right-out only driveways with full access provided on adjacent minor or side street roadways shall be considered when proposed site access driveways are proposed in locations near a major signalized intersection.	Ch. 3, Sec. 3B-2, Fig. 3-2, pg. 21
Driveway Width Provide reference to crash rate results from SCDOT sponsored research	Selection of appropriate driveway width is a crucially important element for driveway access design, as this factor has a considerable effect on safety and crash rates per findings from SCDOT sponsored research shown in Figure 4.17.	Ch. 3, Sec. 3B-2, pg. 21
Driveway Widths and Radii Add contextual information on safety and design, in text and/or in Table footnote	Determination of driveway design dimensions should include engineering consideration of the following: 1. Shared driveways are highly encouraged. 2. Dual entrance lanes configured separately for right turn in and left turn in should be considered for high and major volume driveways as SCDOT sponsored research findings clearly show higher crash rates result for these driveway classifications when only a single entrance lane is provided. 3. Access designs including continuous driveways or mountable curbs shall be avoided as increased conflict areas are created	Ch. 3, Sec. 3B-2, Tb. 3-4, Pg. 22

	and SCDOT sponsored research findings clearly show high crash rates result from these configurations. 4. Right-in, right-out only driveways with full access provided on adjacent minor or side street roadways shall be considered when proposed site access driveways are proposed in locations near a major signalized intersection.	
Right-in, Right-out Driveways Provide reference to crash rate results from SCDOT sponsored research	Use of right-in, right-out driveways versus full access driveways especially for high-turnover land uses is a crucially important element for driveway access design, as this factor has a considerable effect on safety and crash rates per findings from SCDOT sponsored research shown in Figures 4.23 and 4.24.	Ch. 3, Sec. 3C-1, pg. 26
Driveway Spacing Provide reference to crash rate results from SCDOT sponsored research	Selection of appropriate driveway spacing is a crucially important element for driveway access design, as this factor has a considerable effect on safety and crash rates per findings from SCDOT sponsored research shown in Figure 4.16.	Ch. 3, Sec. 3C-1, pg. 26
Minimum Driveway Spacing Add contextual information on safety and design, in text and/or in Figure footnote	Determination of minimum driveway spacing should include engineering consideration of the following: 1. Literature from a variety of highway safety organizations and other State DOT's confirm the SCDOT sponsored research findings that identified driveway spacing as a critical component in safe traffic operations, with adherence to established minimum standards, as a key to lower crash rates related to access. 2. Shared driveways are highly encouraged. 3. Right-in, right-out only driveways are highly encouraged along major roadways, with full access driveways to the proposed site development provided on minor or side street roadways. 4. Only in extraordinary circumstances shall the RE consider exceptions to the minimum driveway spacing stipulated for identified roadway categories shown above.	Ch. 3, Sec. 3C-1, Fig. 3-7, Pg. 27
Corner Clearances Provide reference to crash rate results from SCDOT sponsored research	Selection of appropriate corner clearance is a crucially important element for driveway access design, as this factor has a considerable effect on safety and crash rates per findings from SCDOT sponsored research shown in Tables 4.7 and 4.8, and Figure 4.22.	Ch. 3, Sec. 3C-2, pg. 28
Corner Clearances Add contextual information on safety and design, in text and/or in Figure footnote	Determination of minimum corner clearances should include engineering consideration of the following: 1. Analysis from SCDOT sponsored research clearly shows that adherence to minimum corner clearance standards is a crucial contributing factor to access related crash rates, and that access related crash rate increases dramatically within 150-ft of a driveway access. 2. Right-in, right-out only driveways with full access provided on adjacent minor or side street roadways shall be considered when proposed site access driveways are proposed in locations near a major signalized intersection. 3. Findings from SCDOT sponsored research findings clearly show that right-in, right-out only driveways are safer and shall be considered for proposed site access near major signalized intersections. 4. Site access configurations that allow use of left turn lanes near an intersection for ingress/egress to driveways should be	Ch 3., Sec. 3C-2, Fig. 3-9, Pg. 29

	avoided. 5. For proposed sites involving high-turnover sites, such as fast food or similar businesses, adherence to minimum corner clearance standards is crucially important to avoid higher crash rate occurrence. 6. Raised medians shall be considered for right-in, right-out only site access driveways along roadways with a center turn lane to eliminate direct driveway ingress/egress from the far-side of the roadway. 7. Only under extraordinary circumstances shall the RE consider exceptions to the minimum corner clearance stipulated for identified driveway categories shown above.	
Access Placement in Interchange Areas Add contextual information on safety and design, in text and/or in Figure footnote	Determination of minimum spacing for freeway interchange areas should include engineering consideration of the following: 1. SCDOT sponsored research findings clearly show that higher crash rates occur along roadways adjacent to freeway interchange areas. 2. Only under extraordinary circumstances shall the RE consider exceptions to the minimum access placement spacing identified in the figure above	Ch 3., Sec. 3C-4, Fig. 3-11, Pg. 30
Shared Driveways Add contextual information regarding shared driveways	SCDOT sponsored research findings clearly show that higher crash rates result from increased driveway density. Shared driveways shall be considered for site access locations. Beneficial safety outcomes from shared driveways include: increased spacing between driveways, reduced driveway density, reduced number of conflict points, rerouting of full access points to adjacent minor or side street roadways, potential to improve off-road site traffic circulation, and potential to increase corner clearance distances. The benefits of shared driveway configurations shall be considered for all high-turnover sites, such as fast food or similar businesses, or proposed site access near major signalized intersections.	Ch 3., Sec. 3C-6, Pg. 31
Medians Provide reference to crash rate results from SCDOT sponsored research	Median type is an important consideration in the selection of appropriate driveway geometric features, adherence to required dimension standards, and provision of optimal lane configurations, as this factors has a considerable effect on safety and crash rates per findings from SCDOT sponsored research shown in Figure 4.13, and Table 4.7.	Ch. 3, Sec. 3D, pg. 32
Median Crossovers Add contextual information regarding safety importance and requirements to list of existing bullet items for requirements	• SCDOT sponsored research findings clearly show that higher crash rates result at access locations with median crossovers. • Site access configurations that include median crossovers without provision for left turn lanes or auxiliary should be avoided. • Only in extraordinary circumstances shall the RE consider exception, via access waivers, to median crossover spacing standards for higher volume roadways, medium to major volume driveways, or near major signalized intersections.	Ch. 3, Sec. 3D-1, pg. 33
Auxiliary Lanes Add contextual information regarding safety importance and requirements	• Site access configurations that allow use of left turn lanes near an intersection or auxiliary lanes for ingress/egress to driveways should be avoided.	Ch. 5, Sec. 5D, Pg. 47
Traffic Impact Studies	SCDOT sponsored research findings clearly show that access design, spacing, circulation, and density for driveways have a considerable	Ch 6., Sec. 6A, Pg. 53

Add contextual information regarding safety	impact on safety and crash rates. Preparation of a TIS should include consideration of safety and possible approaches to mitigate potential crash rate increases associated with access/driveway designs. TIS should include consideration of shared driveways, right-in, right-out only driveways, rerouting of full access points to adjacent minor or side or rear street roadways, potential to improve off-road site traffic circulation, and potential to increase corner clearance distances, particularly for major signalized intersections.	
Traffic Impact Studies Update technical reference	Transportation Impact Analyses for Site Development: An ITE Recommended Practice, Institute of Transportation Engineers, 2010.	Ch. 6, Sec. 6B, pg. 55
Traffic Impact Studies Add contextual information regarding safety in introduction of study requirements	SCDOT sponsored research findings clearly show that access design, spacing, circulation, and density for driveways have a considerable impact on safety and crash rates. Projected volumes are a critical component of access safety and for maintaining lower access crash rates. Studies should include consideration of projected long-term horizon traffic volumes and the effect on safe access for the proposed site development. Additionally, studies should address corridor access and access safety including consideration of other programmed or planned site developments anticipated to occur along emerging development-orientated corridors.	Ch. 6, Sec. 6B, pg. 55
Traffic Impact Studies Insert an additional item to requirements for traffic impact studies	10. The traffic impact study should include proposed improvements or access management techniques that will mitigate any significant changes in the levels of services. Additionally the traffic impact study should include consideration of opportunities to enhance access/driveway safety and improve access circulation.	Ch. 6, Sec. 6B, Item 10, pg. 56
Pavement Markings Add contextual information regarding safety	SCDOT sponsored research findings clearly showed driver confusion and erratic driver behavior occurring where double double yellow lines were present, which shall be avoided for proposed site access plans. Raised medians are preferable for these locations from a safety perspective.	Ch. 8, Sec. 82, pg. 73

Adoption of these changes and modifications to SCDOT ARMS, update or revision of existing documents, should lead to better practices by property owners and site developers who are seeking to gain access to the state roadway network. Additionally, specific provisions refining the type conditions and locations for which waivers can be considered for design of access and issuance of encroachment permits, should lead to further improvements in safety for the traveling public.

7.3 Implementation Plan

Implementation of the recommendations presented in this report will require adoption of new operating procedures for each SCDOT district, personnel training and other related resources. Possible benefits include enhanced centralized management of access waiver application data, long-term economic benefits, and improved traffic flow and safety. It is anticipated that this access management program will be shared with municipalities so that access management can be included in initial municipal planning. An implementation plan for recommendations identified in this report should be further evaluated through the following tasks:

<u>Task 1: Improvement to Access Waivers</u>. While the current paper based process suffices it is

evident based on our literature review and discussion in Chapter 2 that this process could be significantly streamlined and enhanced. Specifically, having a state-wide centralized database of waiver applications such as the one being used by Oregon DOT would greatly reduce the time it takes to process an application, allow for sharing of data, knowledge and expertise between resident engineers, and most importantly, provide a single repository of waivers across the state which would then allow for easy retrieval of data for safety and access management analyses. The design of this system could be a collaborative effort done in house. The information that is currently collected could be enhanced with data collected by others states including the Oregon DOT "CHAMPS" system. See Section 8.4 for additional suggestions for enhancing access waiver procedures.

Task 2: Review and implementation changes to the ARMS Manual. The recommended changes to the ARMS manual should be reviewed by appropriate SCDOT personnel and revisions should be made based on SCDOT practice for implementing and formally adopting standards.

Task 3: Modification of RIMS. Consider modifying RIMS to include point locations of driveways throughout the state. Point locations are sufficient for developing crash rates that can be used to identify potential hot spots. Selected driveway characteristics most critical to safety analysis could also be populated as attributes for more robust safety analysis.

Task 4: Procedures for monitoring Driveway Safety. Establish procedures for monitoring safety of driveways throughout the state. The methods discussed in this report can be used to determine crash rates for driveways throughout the state. Crash modification factors and functions can be used to identify safety benefits of implementing counter measures.

Task 5: Training. Assess and develop plan for in-house personnel training to institute new procedures related access waiver process, changes to the ARMS Manual, and in-house analysis of driveway crash data.

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CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS

The primary goal of this research is to improve SCDOT access management practices resulting in a reduction in crashes, injuries, and fatalities on South Carolina roadways. The anticipated enhanced safety will also improve traffic operations by reducing conflicts. The results of the research highlight a close relationship between driveway characteristics and the incidence of crashes. Thus, it is critical that South Carolina is proactive in enforcing access management strategies and policies that are designed to enhance driveway safety and operations without compromising the economic vitality of land use along roads in South Carolina. Based on this research, there are several conclusions and recommendations that are highlighted in the next several sections.

8.1 Literature Review

The literature review presented in Chapter 2 indicates that there is a vast amount of information available related to access management strategies and policies that have been implemented around the country and abroad. Many of these strategies have already been implemented in South Carolina and are published in the latest ARMS manual. The findings of the literature review greatly influenced the research as well as recommended changes to the ARMS manual identified in Chapter 7. Because of the variety of approaches to access management from state to state not all of the "best practices" are included in the recommended access management program presented in Chapter 7. It is recommended that SCDOT thoroughly review the literature review presented in Chapter 2 and follow up with transportation agencies from other states where appropriate to help guide changes to SCDOT's current access management program as well as modifications to the ARMS manual.

8.2 Accuracy of Crash Data

Using empirical data collected along several corridors that ranked highest in driveway related crashes, the researchers statistically analyzed and identified the correlation of access issues with crash data from 2012. Historical crash data before 2012 were not used in the final analyses because of spatial accuracy problems with the previous crash reporting procedures that based the location of crashes on the coordinates from handheld Global Positioning System (GPS) receivers. One of the issues of using GPS receivers to geocode a crash is that the coordinates recorded in the crash report are, in most cases, where the report is filled out rather than where the crash actually occurred. Recent implementation of new statewide crash reporting initiatives in South Carolina and, in particular, GIS-based maps enabled with GPS known as SCCATTS have vastly improved the accuracy and quality of crash data in South Carolina allowing more robust safety analysis. GIS spatial analysis and case study tabulations support this finding as poor geocoding in the 2010 indicated that more that 50% of the crash locations (not including run-off-the-road and fixed object crashes) occur outside the travel way while the 2011 and 2012 data indicated that the proportion of crashes occurring within the travel way is nearly 100%. The case study analysis of crash data incidence in close proximity to intersections failed to identify numerous driveway crash clusters, while 2012 data readily revealed these patterns. Improved accuracy in crash data is greatly benefiting this research with the ability to associate driveways with crashes which was key to the development of driveway crash rates and the statistical analysis. Additionally, improved crash data quality will enhance other types of safety analysis such as more effective identification and prioritization of specific problem roadway locations and appropriate safety countermeasures.

As a result of the new crash reporting procedures, South Carolina has made great strides to improve crash data quality within the state. Although highway patrol officers are equipped SCCATTS, a large number of jurisdictions continue to use hand-held GPS units and paper crash reports. Currently, only 60 percent of statewide crashes are reported using SCCATTS. The next steps in the SCDPS and SCDOT effort to collect high accuracy crash data statewide would be to push for the use of SCCATTS in jurisdictions that are not currently using the system. In order to accomplish this goal, SCDOT would first have to educate local officials and law enforcement officers on the benefits of using SCCATTS. The ability to collect spatially accurate statewide crash data in South Carolina will enable the SCDOT in conducting data-driven transportation safety analysis as well as foster other transportation related research resulting in more effective safety programs and policies.

8.3 Analysis of Driveway Crashes

It was evident as the safety analyses were undertaken that some analyses had to be changed or removed from the original scope of work due to a variety of circumstances including spatial inaccuracy of crash data prior to 2011, and limitations in the available access waiver data on corridors with a high number of driveway crashes. Thus, the focus of the analysis was cross-sectional using 2012 crash data and detailed driveway characteristics. The study team put in countless hours in the development of the driveway database for 11 selected corridors from all over the state. Input from the South Carolina Access and Roadside Management Standards (ARMS) and the Highway Safety Manual (HSM) were used as guides in the selection of attributes for each driveway. Six corridors were selected for the final statistical analysis.

The analysis in Chapter 4 identified several significant independent variables that influence crash rates either positively or negatively. The results indicate that increasing the distance between driveways, increasing the number of entry lanes, and having a raised median will decrease driveway related crashes. Conversely, increasing driveway width, corridor volume and corridor speed limit will increase crashes. Similarly, a driveway with high turnover land use, a driveway with full access (as opposed to right-in right-out), and the presence of nearby signalized intersections will increase crashes. Thus, it is very important that the type of landuse and the context of the road be considered in the design of site access. Crash Modification Factors and functions identified in the literature are in general agreement with research findings on this project. The results of the statistical analysis was the bases for many of the recommended changes to the ARMS manual discussed in Chapter 7.

8.4 Access Waiver Procedures

In South Carolina, the current practice in requesting an access waiver is that the applicant manually completes the request form (in Appendix C of the SCDOT ARMS Manual, 2008) and attaches it to the permit application. The waiver application is then sent to the District Office for initial review and approval by the District Engineering Administrator (DEA). Once approved by the DEA, the access waiver is sent back to the County Maintenance Office for a final review.

The Resident Maintenance Engineer makes the final approval. The entire waiver application process is paper based. Each county in South Carolina manages the waiver application in a similar manner. While the current process suffices it is evident based on our literature review and discussion in Chapter 2 that this process could be significantly streamlined and enhanced. Specifically, having a state-wide centralized database of waiver applications such as the one being used by Oregon DOT would greatly reduce the time it takes to process an application, allow for sharing of data, knowledge and expertise between resident engineers, and most importantly, provide a single repository of waivers across the state which would then allow for easy retrieval of data for safety and access management analyses.

In addition to the aforementioned administrative change, a procedural change is also recommended for the access waiver process. While it is understood that the DEA considers each waiver on a case-by-case basis, it is imperative that he/she recognizes the implications of driveways when placed in certain locations. The following table highlights situations that have low, medium, and high risk of granting waivers for driveways that violate standards.

Risk	**Situation**
Low	Low volume on corridor (AADT < 10K), low turnover land use (residential), driveway far from intersection (> 300 feet), corridor has raised or grass median, right-in-right-out driveways
Medium	Medium volume on corridor (10K ≤ AADT ≤ 20K), medium turnover land use (small offices, small sit-down restaurants), driveway close to intersection (< 150 feet), single, double, or double-double painted median
High	High volume on corridor (AADT > 20K), high turnover land use (fast food restaurants, gas stations, drive-through banks), driveway close to busy intersection (< 150 feet), auxiliary left turn lanes intended for use at intersections that have high potential for use by proposed driveway.

For situations that are classified as medium or high risk, the granting of access waivers is not recommended. Furthermore, a driveway that generates a design hourly volume in excess of 100 vehicles should be required to include a traffic impact study that not only looks at traffic operations, but also examines safety implications and various approaches to mitigate potential crashes associated with the proposed driveway design. Additional consideration should be made for a land use where predicted growth along the corridor may cause substantial increases in future traffic volumes.

The risk categories were developed based on the analysis results of this research as well as findings from the literature review. For example, the AADT categories are derived from the safety performance function graph presented in Figure 4.19 which shows 3 distinct areas—a relative low predicted driveway crash rate for roads less than 10, 000 AADT, a higher rate/slope between 10,000 AADT and 20,000, and a rapidly increasing slope above 20,000 AADT.

8.5 Operational Analysis

In current practice, states have adopted differing minimum driveway spacing guidelines and these values are based on a variety of criteria, such as volume on the adjacent roadway, trip generation from driveways, posted speed limit, land use, and access type. This study used VISSIM, a micro-simulation tool, to investigate the operational performance of different driveway spacing policies adopted by various DOTs in the US. Experimental results indicate that driveway spacing has direct influence on the average travel speed of a corridor. Since reduced driveway spacing negatively impact corridor travel speed, selection of a minimum spacing should consider its effect on the operational performance of the corridor.

8.6 Economic Analysis

Benefit-cost analyses of two different access modification strategies following the Highway Safety Manual (HSM) procedures suggest that it is beneficial to convert a TWLTL to a raised median. Similarly, it is beneficial to reduce the driveway density on a corridor. The HSM analysis used in this study only considered safety benefits of access management strategies. It did not consider the impact of different access management strategies on surrounding businesses.

8.7 Enhancements to South Carolina's Access Management Program

The South Carolina Access and Roadside Management Standards (ARMS) provides standards and guidelines for permitting access encroachments onto SCDOT right-of-way. The research has identified a number of recommended changes that could result in a reduction in crashes, injuries, and fatalities on South Carolina roadways. Adoption of these changes and modifications to SCDOT ARMS should lead to better practices by property owners and site developers who are seeking to gain access to the state roadway network. Additionally, specific provisions refining the type conditions and locations for which waivers can be considered for design of access and issuance of encroachment permits, should lead to further improvements in safety for the traveling public.

8.8 Summary

The data driven approach to the safety analysis has resulted in several research findings with regard to the relationship between safety and access management. These findings have resulted in the development of an implementation plan to improve access management practices in South Carolina. It is anticipated that implementation of the findings of this research will result in long-term economic benefits, and improved traffic flow and safety. It is anticipated that this access management program will be shared with municipalities so that access management can be included in initial municipal planning.

8.9 Recommendations for Further Research

The enhanced crash data spatial accuracy will result in enhanced future safety analysis including the analysis of driveway data. Longitudinal before and after studies of driveway safety countermeasures, new developments with access waivers, as well as trend analysis after implementation of changes to access management practices resulting from this research are all potential research opportunities that can benefit the state. A follow-up research project sponsored by South Carolina Department of Transportation will investigate additional factors that impact operations, such as the effect of different driveway configuration, variation in driveway and mainline traffic volume, and corridor speed. The HSM analysis used in this study only considered safety benefits of access management strategies. It did not consider the impact of different access management strategies on surrounding businesses. The follow-up project will investigate these aspects in detail.

APPENDIX: CRASH MODIFICATION FACTORS – FULL REFERENCES

1.0 Signal Spacing/Density

Change in Signal Spacing from X 1000's feet to Y 1000's feet

Source: CMF Clearinghouse (3*) – Mauga, T. and Kaseko, M. (2010)

Abstract: This paper presents results of a study that developed statistical models that relate access management (AM) features with traffic safety in midblock sections of street segments. The objective of the study was to evaluate and quantify the impact of the AM features on traffic safety in the midblock sections. It is anticipated that the results of this study will assist local jurisdictions in the Las Vegas valley in the development of new AM policies and programs. Models were calibrated for two main types of median treatments for street segments, namely, raised medians (RM) and two-way-left-turn-lanes (TWLTL). Other AM features considered were signal spacing and the densities of driveways, median openings and unsignalized cross roads. Separate models were developed for the impacts on total crash rates, types of crashes and severity. The study results confirmed the intuitive expectation that these AM features do have significant impact on safety. They show that segments with RM had lower crash rate by 23% compared to segments with TWLTL. The results also show that higher densities of driveways cross roads and median openings results in higher crash rates and severity. For example, for segments with RM, each additional median opening per mile results in a 4.7% increase in the total crash rate. A comparison of these results with pervious similar studies is also made in this paper.

CMF = $e^{-0.1276(Y-X)}$

Where Y = Signal spacing in post condition

X = Signal spacing in pre condition

Applicability:

Crash Type:	Angle, Fixed object, Head on, Rear end, Run off road, Sideswipe, Single vehicle
Crash Severity:	All
Road Type:	All
Roadway Division:	Divided by Median
Speed Limit:	30 -45
Area:	Urban
Traffic Volume:	29320 - 96080

Change the Natural Log of the Downstream Distance to the Nearest Signalized Intersection for an Unsignalized 3-leg Intersection from X to Y

Source: CMF Clearinghouse (3*) – Haleem, K. and Abdel-Aty, M. (2011)

Abstract: In this paper, we propose a new promising machine learning technique to select important explanatory covariates, as well as to improve crash prediction; the group least absolute shrinkage and selection operator (GLASSO) technique. GLASSO's main strength lies in its ability to deal with datasets having relatively large number of categorical variables, which is the case in this study. Identifying the significant factors affecting safety of unsignalized intersections was also an essential objective. Two applications of GLASSO were investigated; application for variable screening before fitting the traditional negative binomial (NB) model, as well as before fitting another promising data mining technique (the multivariate adaptive regression splines "MARS"). Extensive data collected at 2475 unsignalized intersections were used. For fitting the NB models, the backward deletion and the random forest techniques were separately used as variables 11 screening, and their prediction performance was compared to that from GLASSO. All the three methods resulted in almost similar predictions. For GLASSO's second application with MARS, the model fitting relatively outperformed that from the random forest technique with MARS, with similar prediction performance. Due to its outstanding performance with categorical variables, as well as its simplicity, GLASSO is recommended as a promising variable selection technique. Significant predictors affecting total crashes at unsignalized intersections were traffic volume on the major road, the upstream and downstream distances to the nearest signalized intersection, median type on major and minor approaches, and type of land use. Resembling previous studies, the volume of traffic was the most important predictor.

CMF = $e^{-0.0345(Y-X)}$

Where Y = Distance post condition

X = Distance pre condition

Applicability:

Crash Type: All

Crash Severity: All

Road Type: Not Specified

Roadway Division: All

Speed Limit: -

Area: All

Traffic Volume: -

Change the Natural Log of the Downstream Distance to the Nearest Signalized Intersection for an Unsignalized 4-leg Intersection from X to Y

Source: CMF Clearinghouse (3*) – Haleem, K. and Abdel-Aty, M. (2011)

Abstract: In this paper, we propose a new promising machine learning technique to select important explanatory covariates, as well as to improve crash prediction; the group least absolute shrinkage and selection operator (GLASSO) technique. GLASSO's main strength lies in its ability to deal with datasets having relatively large number of categorical variables, which is the case in this study. Identifying the significant factors affecting safety of unsignalized intersections was also an essential objective. Two applications of GLASSO were investigated; application for variable screening before fitting the traditional negative binomial (NB) model, as well as before fitting another promising data mining technique (the multivariate adaptive regression splines "MARS"). Extensive data collected at 2475 unsignalized intersections were used. For fitting the NB models, the backward deletion and the random forest techniques were separately used as variables 11 screening, and their prediction performance was compared to that from GLASSO. All the three methods resulted in almost similar predictions. For GLASSO's second application with MARS, the model fitting relatively outperformed that from the random forest technique with MARS, with similar prediction performance. Due to its outstanding performance with categorical variables, as well as its simplicity, GLASSO is recommended as a promising variable selection technique. Significant predictors affecting total crashes at unsignalized intersections were traffic volume on the major road, the upstream and downstream distances to the nearest signalized intersection, median type on major and minor approaches, and type of land use. Resembling previous studies, the volume of traffic was the most important predictor.

CMF = $e^{-0.4815(Y-X)}$

Where Y = Distance post condition

X = Distance pre condition

Applicability:

Crash Type: All

Crash Severity: All

Road Type: Not Specified

Roadway Division: All

Speed Limit: -

Area: All

Traffic Volume: -

2.0 Access Points

Absence of Access Points	
Source:	CMF Clearinghouse (3*) – Lee et al. (2011)
Finding:	This study analyzes the crashes that occur at mid-block called “mid-block crashes” in an urban arterial road. The association of mid-block crashes with various factors was examined using the 7-year (2000-2006) crash data on a section of a divided arterial road in Windsor, Ontario, Canada. To account for difference in traffic volume and road geometric factors between two directions of travel in a divided road, the data were collected for two directions separately. The results of log-linear models using these bidirectional data show that mid-block crashes are more likely to occur on the road sections with access point and high percentage of truck (> 20%). It was also found that the effects of access point and truck percentage were not statistically significant when the unidirectional data were used. A sensitivity analysis was also performed to identify the bidirectional variables affecting crash frequency by direction. It was found that the difference in truck percentage between two directions can most effectively reflect the difference in crash patterns by direction. The results of logistic regression models show that median opening, driver age/gender, lighting, time of day and day of week are associated with different types of crashes classified by the vehicles involved in crashes. The study shows the importance of analyzing mid-block crashes using the bidirectional data by vehicle type in urban divided arterial roads with high truck volume.
CMF =	0.56
Applicability:	
Crash Type:	All
Crash Severity:	All
Road Type:	Principle Arterial Other
Roadway Division:	Divided by Median
Speed Limit:	-
Area:	Urban
Traffic Volume:	-

Change Driveway Density from X to Y Driveways per Mile

Source: CMF Clearinghouse (3*) – Fitzpatrick et al. (2009)

Abstract: Agencies are seeking a better understanding of those roadway or roadside features that affect safety. The objectives of this study were to develop a horizontal curve accident modification factor (AMF) for rural, four-lane divided and undivided highways and to determine if the effect of driveway density is different for horizontal curves as compared to tangent sections. Data available for use in the evaluation included 121 centerline miles of rural, four-lane highways. Negative binomial regression models were used to determine the effects of independent variables on crashes. Variables considered in developing the base models included driveway density, lane width, outside shoulder width, median width (which included inside shoulder width), median type, degree of curve, segment length, and average daily traffic. Five years (1997-2001) of driveway and segment crashes were examined. An AMF for horizontal curves was estimated and it supports a theoretical model developed in another study. Reviewing the findings with respect to driveway density revealed that the effect of driveway density is different for horizontal curves and tangents; however, the differences were relatively minor. Therefore, the driveway density AMF determined using both the horizontal curve and tangent sections is recommended.

CMF = $e^{0.0152(Y-X)}$

Where Y = # of driveways per mile in post condition

X = # of driveways per mile in pre condition

Applicability:

Crash Type: All

Crash Severity: Fatal, Serious injury, Minor injury

Road Type: Principle Arterial Other

Roadway Division: -

Speed Limit: -

Area: Rural

Traffic Volume: -

Change Driveway Density from X to Y (driveways/mile for segment)

Source: CMF Clearinghouse (3*) – Fitzpatrick et al. (2008)

Abstract: The accident modification factors (AMFs) for driveway density can be described as the incremental effects of driveway density on safety. The objective of this study was to develop AMFs for driveways on rural highways in Texas. For rural, two-lane highways, 2354 miles were available and 402 centerline miles were available for rural, four-lane highways evaluations. Based on a review of the data, it is recommended that the assumed base condition for driveway density be 3 driveways/mile. Negative binomial regression was used to determine the effects of independent variables on crashes. Crashes were examined in terms of driveway and segment crashes for three years (1999-2001). AMF equations that consider the driveway density for the segment were developed for both rural, two-lane and four-lane highways.

CMF = $e^{0.0232(Y-X)}$

Where Y = # of driveways density in post condition

X = # of driveways density in pre condition

Applicability:

Crash Type: All

Crash Severity: All

Road Type: Principle Arterial Other

Roadway Division: -

Speed Limit: -

Area: Rural

Traffic Volume: -

Change Driveway Density from X to Y Driveways per Mile	
Source:	CMF Clearinghouse (3*) – Mauga, T. and Kaseko, M. (2010)
Abstract:	This paper presents results of a study that developed statistical models that relate access management (AM) features with traffic safety in midblock sections of street segments. The objective of the study was to evaluate and quantify the impact of the AM features on traffic safety in the midblock sections. It is anticipated that the results of this study will assist local jurisdictions in the Las Vegas valley in the development of new AM policies and programs. Models were calibrated for two main types of median treatments for street segments, namely, raised medians (RM) and two-way-left-turn-lanes (TWLTL). Other AM features considered were signal spacing and the densities of driveways, median openings and unsignalized cross roads. Separate models were developed for the impacts on total crash rates, types of crashes and severity. The study results confirmed the intuitive expectation that these AM features do have significant impact on safety. They show that segments with RM had lower crash rate by 23% compared to segments with TWLTL. The results also show that higher densities of driveways cross roads and median openings results in higher crash rates and severity. For example, for segments with RM, each additional median opening per mile results in a 4.7% increase in the total crash rate. A comparison of these results with pervious similar studies is also made in this paper.
CMF =	$e^{0.0096(Y-X)}$
	Where Y = # of driveways per mile in post condition X = # of driveways per mile in pre condition
Applicability:	
Crash Type:	Angle, Fixed object, Head on, Rear end, Run off road, Sideswipe, Single vehicle
Crash Severity:	All
Road Type:	All
Roadway Division:	Divided by Median
Speed Limit:	30 -45
Area:	Urban
Traffic Volume:	29320 - 96080

3.0 Two-Way-Left-Turn

Add Two-Way-Left-Turn-Lane (TWLTL) to the Major Approach of an Unsignalized 3-leg Intersection

Source: CMF Clearinghouse (3*) – Haleem and Abdel–Aty (2010)

Abstract: In this paper, we propose a new promising machine learning technique to select important explanatory covariates, as well as to improve crash prediction; the group least absolute shrinkage and selection operator (GLASSO) technique. GLASSO's main strength lies in its ability to deal with datasets having relatively large number of categorical variables, which is the case in this study. Identifying the significant factors affecting safety of unsignalized intersections was also an essential objective. Two applications of GLASSO were investigated; application for variable screening before fitting the traditional negative binomial (NB) model, as well as before fitting another promising data mining technique (the multivariate adaptive regression splines "MARS"). Extensive data collected at 2475 unsignalized intersections were used. For fitting the NB models, the backward deletion and the random forest techniques were separately used as variables 11 screening, and their prediction performance was compared to that from GLASSO. All the three methods resulted in almost similar predictions. For GLASSO's second application with MARS, the model fitting relatively outperformed that from the random forest technique with MARS, with similar prediction performance. Due to its outstanding performance with categorical variables, as well as its simplicity, GLASSO is recommended as a promising variable selection technique. Significant predictors affecting total crashes at unsignalized intersections were traffic volume on the major road, the upstream and downstream distances to the nearest signalized intersection, median type on major and minor approaches, and type of land use. Resembling previous studies, the volume of traffic was the most important predictor.

CMF = 0.69

Applicability:

Crash Type:	All
Crash Severity:	All
Road Type:	Not Specified
Roadway Division:	-
Speed Limit:	-
Area:	All
Traffic Volume:	-

Add Two-Way-Left-Turn-Lane (TWLTL) to the Major Approach of an Unsignalized 4-leg Intersection	
Source:	CMF Clearinghouse (3*) – Haleem and Abdel–Aty (2010)
Abstract:	In this paper, we propose a new promising machine learning technique to select important explanatory covariates, as well as to improve crash prediction; the group least absolute shrinkage and selection operator (GLASSO) technique. GLASSO's main strength lies in its ability to deal with datasets having relatively large number of categorical variables, which is the case in this study. Identifying the significant factors affecting safety of unsignalized intersections was also an essential objective. Two applications of GLASSO were investigated; application for variable screening before fitting the traditional negative binomial (NB) model, as well as before fitting another promising data mining technique (the multivariate adaptive regression splines "MARS"). Extensive data collected at 2475 unsignalized intersections were used. For fitting the NB models, the backward deletion and the random forest techniques were separately used as variables 11 screening, and their prediction performance was compared to that from GLASSO. All the three methods resulted in almost similar predictions. For GLASSO's second application with MARS, the model fitting relatively outperformed that from the random forest technique with MARS, with similar prediction performance. Due to its outstanding performance with categorical variables, as well as its simplicity, GLASSO is recommended as a promising variable selection technique. Significant predictors affecting total crashes at unsignalized intersections were traffic volume on the major road, the upstream and downstream distances to the nearest signalized intersection, median type on major and minor approaches, and type of land use. Resembling previous studies, the volume of traffic was the most important predictor.
CMF =	0.66
Applicability:	
Crash Type:	All
Crash Severity:	All
Road Type:	Not Specified
Roadway Division:	-
Speed Limit:	-
Area:	All
Traffic Volume:	-

Convert an Open Median to a TWLTL

Source: CMF Clearinghouse (3*) – Haleem, K., Abdel-Aty, M., and Mackie, K. (2010)

Abstract: The negative binomial (NB) model has been used extensively by traffic safety analysts as a crash prediction model, because it can accommodate the over-dispersion criterion usually exhibited in crash count data. However, the NB model is still a probabilistic model that may benefit from updating the parameters of the covariates to better predict crash frequencies at intersections. The objective of this paper is to examine the effect of updating the parameters of the covariates in the fitted NB model using a Bayesian updating reliability method to more accurately predict crash frequencies at 3-legged and 4-legged unsignalized intersections. For this purpose, data from 433 unsignalized intersections in Orange County, Florida were collected and used in the analysis. Four Bayesian-structure models were examined: (1) a non-informative prior with a log-gamma likelihood function, (2) a non-informative prior with an NB likelihood function, (3) an informative prior with an NB likelihood function, and (4) an informative prior with a log-gamma likelihood function. Standard measures of model effectiveness, such as the Akaike information criterion (AIC), mean absolute deviance (MAD), mean square prediction error (MSPE) and overall prediction accuracy, were used to compare the NB and Bayesian model predictions. Considering only the best estimates of the model parameters (ignoring uncertainty), both the NB and Bayesian models yielded favorable results. However, when considering the standard errors for the fitted parameters as a surrogate measure for measuring uncertainty, the Bayesian methods yielded more promising results. The full Bayesian updating framework using the log-gamma likelihood function for updating parameter estimates of the NB probabilistic models resulted in the least standard error values.

CMF = 1.45

Applicability:

Crash Type:	All
Crash Severity:	All
Road Type:	Not Specified
Roadway Division:	-
Speed Limit:	-
Area:	Not Specified
Traffic Volume:	-

4.0 Raised Median

Install Raised Median	
Source:	CMF Clearinghouse (4*) – Schultz, G., Thurgood, D., Olsen, A., Reese, C.S. (2011)
Abstract:	Because traffic safety studies are not performed in a controlled environment such as a laboratory, but rather in an uncontrolled real world setting, traditional analysis methods often lack the capability to adequately evaluate the effectiveness of roadway safety measures. In recent years, however, advanced statistical methods have been utilized in traffic safety studies to more accurately determine the effectiveness of such measures. These methods, particularly Bayesian statistical techniques, have the capabilities to account for the shortcomings of traditional methods. Hierarchical Bayesian modeling is a powerful tool for expressing rich statistical models that more fully reflect a given problem than traditional safety evaluation methods could. This paper uses a hierarchical Bayesian model to analyze the effectiveness of raised median installations on overall and severe crash frequency in the state of Utah by determining the effect each has on crash frequency and frequency of severe crashes at study locations before and after installation of raised medians. Several sites where raised medians have been installed in the last 10 years were evaluated using available crash data. The results of this study show that the installation of a raised median is an effective technique to reduce the overall crash frequency and frequency of severe crashes on Utah roadways with results showing a reduction in overall crash frequency of 25 percent and frequency of severe crashes of 36 percent along corridors where raised medians were installed. The results also show that hierarchical Bayesian modeling is a useful method for evaluating effectiveness of roadway safety measures.
CMF =	0.61
Applicability:	
Crash Type:	All
Crash Severity:	All
Road Type:	Not Specified
Roadway Division:	Divided by Median
Speed Limit:	-
Area:	-
Traffic Volume:	10000 – 55000 ADT

Replace TWLTL with Raised Median	
Source:	CMF Clearinghouse (3*) – Mauga, T. and Kaseko, M. (2010)
Abstract:	This paper presents results of a study that developed statistical models that relate access management (AM) features with traffic safety in midblock sections of street segments. The objective of the study was to evaluate and quantify the impact of the AM features on traffic safety in the midblock sections. It is anticipated that the results of this study will assist local jurisdictions in the Las Vegas valley in the development of new AM policies and programs. Models were calibrated for two main types of median treatments for street segments, namely, raised medians (RM) and two-way-left-turn-lanes (TWLTL). Other AM features considered were signal spacing and the densities of driveways, median openings and unsignalized cross roads. Separate models were developed for the impacts on total crash rates, types of crashes and severity. The study results confirmed the intuitive expectation that these AM features do have significant impact on safety. They show that segments with RM had lower crash rate by 23% compared to segments with TWLTL. The results also show that higher densities of driveways cross roads and median openings results in higher crash rates and severity. For example, for segments with RM, each additional median opening per mile results in a 4.7% increase in the total crash rate. A comparison of these results with pervious similar studies is also made in this paper.
CMF =	0.77
Applicability:	
Crash Type:	Angle, Fixed object, Head on, Rear end, Run off road, Sideswipe, Single Vehicle
Crash Severity:	All
Road Type:	All
Roadway Division:	All
Speed Limit:	30 - 45
Area:	Urban
Traffic Volume:	4883 to 96080